PROCESS ANALYSIS OF MARGARINE AND TABLESPREAD CRYSTALLIZATION OPERATIONS

A Thesis

by

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ABSTRACT

Process Analysis of Margarine and Tablespread
Crystallization Operations.
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An investigation was conducted into the crystallization operations of margarine and tablespread food products. This study utilized equipment settings and engineering parameters as analysis factors on three formulations with oil levels of 80, 50 and 40%. Primary equipment settings of heat exchanger surface area, process flowrate, and rotational speed of the scraped-surface heat exchanger (SSHE) have significant impact, while rotational speed of the secondary unit (B-unit, whipper, etc.) has demonstrated little effect on product attributes of complex viscosity and cone penetration depth.

In addition to process experimentation, a procedure has been verified for quantifying shear in process equipment. This procedure was used for estimating the average shear rate in the SSHE used in the process study. Knowledge of process shear rate has allowed for analysis of process operations using engineering parameters, which are not restricted to equipment geometry or scale. In particular, the effects of the secondary unit operation on cone penetration and complex viscosity were quantified, which were not demonstrated in the equipment settings analysis.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A. Background

The use of butter in the diet has been a long tradition in our society. Starting in the 1950's, a substitute for butter took shape based on an emulsion of non-dairy fat. Around the turn of the century, the average American individual consumed about 20 pounds of butter and less than 1.5 pounds of margarine per year. Current consumption of margarine has jumped to an average of 10.5 pounds, while butter has dropped to 4.6 pounds per person, per year (Anonymous, 1989)* . Margarine has grown into a food commodity with its own identity, with butter serving more often as a gourmet item. A primary motivation for this change has been the significantly lower cost of margarine compared to butter. Margarine utilizes primarily inexpensive vegetable oils, while butter is made from expensive milk fat. Other driving factors contributing to margarine growth are the health aspects. Vegetable oil margarines are healthier than butter, due to the lack of cholesterol and lower saturated fat content than milk derived products.

The margarine and tablespread industry has annual sales of 1.6 million tons, with value in the range of 2.5 billion dollars a year. This food industry segment remains flat in growth, with stick margarine losing sales while tub and lower fat products continue to expand (DiPietro, 1989). Consumer demands calling for healthy products have recently resulted in renewed manufacturer interest in the fat-based tablespreads. In particular, efforts have been made to reduce oil/fat levels in the tablespreads. Margarine traditionally has 80% oil, with many newer

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* References in this document follow the format established in the Journal of Food Process Engineering.

products on store shelves having levels of 60, 50 , and even as low as 40% oil in the emulsion. A standard of identity exists for margarine products, with the primary stipulation being that the product contain 80% oil. Margarine-like products with lower oil content emulsions are known in the industry as "tablespreads". Because of significant differences in processing, this study will concentrate only on tub-filled products and not the "stick" type products.

The technology and manufacture of margarine and tablespreads has become relatively uniform among producers of these products, with few significant changes made in the past 20 years. Equipment manufacturers typically serve as system (process) engineers for product manufacturers, and with few suppliers, the technology is well understood. At present, differences which consumers discern in tablespread products are primarily due to ingredient formulations.

Current processing operations for margarine and tablespread products have not been the result of careful engineering, rather the result of "tweaking" equipment to get a desirable product. Therefore, when there is a process upset or new products are being developed, there can be considerable difficulties with little information to work from. Current efforts in new process development and process optimization/cost reduction are now experiencing difficulties due to the lack of fundamental engineering knowledge on the margarine and tablespread product attributes.

B. Purpose

Proper engineering analysis methods of the processing of margarine and tablespreads, specifically the crystallization stage, will aid in designing/selecting equipment and operating conditions for new/improved products. These techniques will also enable current products to be produced with more desirable properties. In addition, the result of this research will allow for cost savings by promoting efficient operation through minimizing down-time and off-spec product.

The overall goal of this research is to define the effects of process history on product attributes, during the oil crystallization stage. Product attributes are those functional characteristics which are important in consumer use, such as spreadability and meltability.

Specific research objectives in this study are:

- To develop a procedure for determining shear characteristics of the process equipment.

- To define the effects of heat exchanger operation on product attributes.

- To define the effects of the secondary unit parameters on product attributes.

- To determine how process effects change between 80, 50 and 40% oil formulations.

The shear history which a process exerts on a fluid element is not well understood for complicated food processing equipment, such as scraped-surface heat exchangers. However, shear is a critical processing parameter, for water-in-oil emulsions. Development of a procedure to quantify shear in a process step is necessary prior to pursuing a process analysis of a tablespread operation.

Operation of heat exchangers and secondary units (whippers, B-units, crystallizers, etc.) has critical effect on crystallization of the oil in the emulsion, which has primary influence on physical product attributes. Effects of heat exchanger and secondary unit operations will be quantified on the basis of particular equipment settings and also critical engineering parameters. Equipment settings are variables that can physically be set on the processing equipment, but are restricted to specific equipment geometry and scale. Engineering parameters for this study are those factors which are important in engineering aspects such as rheology, fluid dynamics, and crystallization kinetics, and are not unique to equipment geometry or scale.

CHAPTER II

LITERATURE REVIEW

Review of prior knowledge for this study has concentrated on three primary areas: margarine manufacture, rheology/texture measurement of margarine, and general methods for determining process shear. Relatively few articles were found which directly apply to the research in question, and those found typically only focus on 80% oil products.

A. Margarine Manufacture

Although production of tablespreads/margarine has been around for over thirty years, there has been little reported process engineering knowledge. Also, nearly all forms of research and published information has been geared toward the 80% oil level products, with little mention of lower oil content tablespreads.

The production of fat-based tablespreads is relatively common technology among the product manufacturers. Except for minor differences, processes are the same among all major manufacturers of these products.

The preparation of the water-in-oil emulsion takes place in a large mixing tank (churn), where all the ingredients are measured into the batch in a precise order over a period of time (see Figure 1). Once a batch is formulated, it is typically pumped to a agitated holding tank. At this point the material has no time dependency as long as it remains agitated and at the correct temperature (~38°C/100°F). The holding tank receives batches of emulsion and feeds into the processing and packing line so that they can operate on a continuous basis.

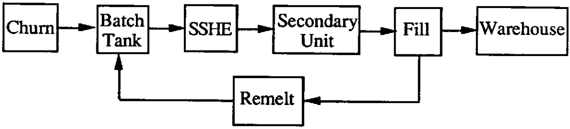

Figure 1.) Simple flow diagram of margarine manufacture.

From the hold tank the material is pumped through a high pressure pump into the scraped surface heat exchanger (SSHE). In the SSHE, the material is rapidly cooled to approximately 10°C (50°F). The SSHE uses a large displacement shaft which occupies up to 80% of the volume, and has several rows of blades for scraping the surface (Haighton, 1976). The close tolerances result in a high amount of shear on the material and for a low residence time of the material in the cooling unit (Whitemarsh, 1989; Opfer, 1978).

The emulsion exits the SSHE at a temperature lower than the crystallization point for the oil, but it takes a period of time for the crystallization reaction to occur. Cooled emulsion exiting the SSHE enters a secondary unit (SU), which acts as an agitated flow-through tank that provides a resting period for the super-cooled emulsion. (The secondary unit is known by many names in the industry, whipper, B-unit, C-unit, etc. The primary difference in these units is the amount of holding volume in relation to the process flowrate. There has not evolved standardized equipment or terminology for this operation, with each group using its own particular nomenclature and equipment for the same basic operation.) Typically the secondary unit is cylindrical in shape, with a concentric rotating shaft in the center, with two rows of small pins perpendicular to the shaft axis which mesh with a single row of pins on the vessel wall. The pins physically agitate and work the product and effect the crystal lattice of the oil (Haighton, 1976). Within the secondary unit the material experiences a temperature rise which is due to the exothermic crystallization (Bolanowski, 1965).

From the exit of the secondary unit the material flows to the packaging line where it is filled into tubs, placed in cartons, and moved to a refrigerated warehouse. Crystallization of margarine and tablespreads continues after filling into containers, but is of small scope compared to the primary effects of the SSHE and secondary unit operations. During start-up, shut-down, and other times when the product is not being packaged, the cooled emulsion is diverted and reheated (remelted) in a heat exchanger where it is then returned to the batch tank.

Recent studies of processing have concentrated on the microstructure of margarine and tablespreads, and have involved the use of a scanning electron microscope to look at effects of process changes (Heertje et al., 1988; Juriaanse and Heertje, 1988). Effect of shear in both the SSHE and secondary units in a small bench-top, laboratory scale process show significant effects on the overall structure of the margarine. The study was conducted in a qualitative manner with reference to structural tendencies as a result of absence or presence of some factor/processing step. Although reference to other measurements is made, discussion is based almost entirely on photomicrographs from electron microscopy, which is a questionable technique. Similar efforts by other researchers using electron microscopy were unable to distinguish crystal structures for a variety of retail margarines (deMan et al., 1989). The conflict in results may be due to difficulties with the electron microscopy or in the use of samples from retail vs. bench-top prepared products.

B. Measurement of Tablespread Attributes

A particular concern with studies of the margarine and tablespreads has been measurement of product attributes. The ideal measurement is one that can be physically quantified, but which closely correlates with attributes consumers use in evaluating the margarine and tablespread products. For example, rheological and thermal melt properties are related to spreading and melting characteristics. These two factors can be described as physical phenomena, and quantitative testing can be conducted that will relate to consumer preference.

1. Thermal Analysis

The measurement of thermal properties is an area that is well established when evaluating tablespread product attributes of different formulations (deMan, 1968; deMan et al., 1976; Taylor and Norris, 1977). Unfortunately these same procedures do not allow for accurate characterization of crystallization as a result of processing. The procedures are designed for analysis of the amount of solid fat (SFI) at a certain temperature after an established thermal treatment of the material. Since this procedure induces a thermal history on the material, the processing effects are removed. The use of a differential scanning calorimeter (DSC), which can be programmed to impart specified time-temperature profiles, is the most commonly used equipment for this type of testing.

Recent advances in the area of nuclear magnetic resonance (NMR) have allowed use of this technology in determining the solid fat content (SFC) of tablespread products. In particular, the use of pulsed NMR differentiates between hydrogen nuclei bound in the solid and liquid phases to determine the amount of solid fat. An important conclusion of studies with NMR is the inability to correlate SFC or SFI values to the degree of crystal networking in the fat (deMan et al., 1989). The use of nuclear magnetic resonance will likely replace other methods for solids determination as NMR equipment becomes more widespread.

2. Rheology/Texture Measurement

The structure and rheological behavior of tablespreads is due in part to formulation, but is primarily the result of the crystallization process history. For a particular formulation, at a given temperature, there will generally always be the same state of oil crystallization. The difference is in the manner which the the oil crystal network was formed. Crystals which are strongly networked together will have significantly different properties than crystals which are more independent in nature. These differences may be differentiated through use of rheology and texture analysis methods.

Characterization of crystallization by rheology and texture measurements has been met with a considerable amount of success (Haighton, 1976; deMan and Beers, 1987). The issue of quantitative texture measurement was first addressed through the use of a cone penetrometer (Haighton, 1959). The use of cone penetrometer procedures has since become the standard within the margarine/tablespreads industry, with the American Society of Oil Chemists' having a formal standard. The standard utilizes a constant force, or drop cone concept in the testing procedure. Investigations have been conducted into the possible use of a constant speed penetrometer, instead of constant force, for testing tablespread products (Tanaka et al., 1971).

Since the penetrometer information gives only a qualitative, somewhat empirical indication of the texture, researchers have investigated other means for characterizing texture. The use of common rheological instruments has been utilized in evaluating texture of the margarine and tablespread products. In particular, cone and plate rotational geometry has been applied in many studies (Cmolik and Stern, 1983; Pokorny et al., 1983; Stern and Cmolik, 1976). With use of rotational geometries there is concern regarding the slip that may take place in testing with high oil-content products, due to the lubricating effect of a thin layer of oil from broken emulsion at the surface. Uniaxial compression has been implemented as a more logical approach since slip is incorporated into the experimental analysis procedure (deMan et al., 1989). Uniaxial compression is also known as parallel plate compression or as squeeze flow, and utilizes a force measurement system (i.e. Instron) to measure force required to squeeze the sample between two plates (Campanella and Peleg, 1987).

Dynamic rheological testing is a well established measurement methodology, and has been successfully applied to testing of margarine and tablespread products (Walters, 1980). Dynamic measurement involves small oscillatory displacements of the test geometry, which vary harmonically with time. A harmonic strain, of some amplitude is applied to one surface of a sample, with an output stress measured on the other surface. Comparison of signals exhibits a phase lag and change in amplitude between the input and output which characterize the rheology of the sample. Two primary factors which are calculated from test information are the storage modulus (G') and loss modulus (G") parameters. The storage modulus is the stress in phase with strain, while the loss modulus is the stress 90° out of phase. Several parameters can be calculated from these two factors, with the most significant being the complex viscosity (η^*). Due to the nature of dynamic testing, it is especially suited for testing products of viscoelastic and semi-solid nature, such as margarine or tablespread products which are considered a classic application.

C. Shear Determination

Shear rates and shear histories are important process parameters which affect the manufacture of water-in-oil emulsions. The engineering approach typically used for calculating shear rates in rotational process equipment is based on an empirical constant multiplied by the angular or tip velocity. Since determination of the empirical constant is not simple, values are often roughly estimated from published values (Cheremisinoff and Gupta, 1983). A procedure has been widely used in estimation of shear rates of non-Newtonian fluids in batch mixers (Metzner and Otto, 1957). This procedure is based on using dimensionless quantities of the mixer power and Reynolds numbers. For mixing of a Newtonian fluid in the laminar region, the power number is inversely related to the Reynolds number. With this information, testing is conducted on known Newtonian and non-Newtonian materials. For a given observation with the non-Newtonian standard, a corresponding power number is determined. This power number is then used to compute a Reynolds number based on the Newtonian power vs. Reynolds number function. The corresponding Reynolds number is then used to compute an apparent viscosity. When the apparent viscosity is compared to the non-Newtonian rheogram for that material, an average shear rate can be determined for that test condition. This concept has been applied in several research situations (Rieger and Novak, 1973; Rao and Cooley, 1984; Mackey et al., 1987). The use of this procedure has recently been adapted for determination of average shear rates in a twin-screw extruder (Mohamed et al., 1989).

CHAPTER III

MATERIALS AND METHODS

A. Shear Determination

Determination of the average shear in margarine and tablespread manufacture was accomplished through use of a procedure described in the literature review section. The SSHE and secondary unit shear characteristics were identified with a series of two tests conducted on the equipment. An agitated holding tank for the material was used with a variable-speed, positive displacement pump configured to pump the material through the process equipment. The testing utilized two different material standards with similar viscosities to the typical process material. (This procedure assumed laminar flow conditions, use of a lower viscosity may have resulted in turbulence.) A Newtonian material (corn syrup) was used for one trial, a non-Newtonian material (Xanthan gum) was utilized in the second trial. For the trials the equipment rotational speed and material flowrate were varied to simulate a variety of conditions. Power input to equipment was measured as accurately as possible since small deviations significantly affected the procedure. Samples were collected of materials during testing for rheological and density measurements.

Pressure drop and temperature change were monitored as part of the test procedure. Presence of significant values for either of these factors required corrections to be made. For significant temperature change through the process unit, rheological properties would be corrected to match the average temperature in the process. For pressure change in the equipment, (i.e. pumping action), the mechanical work input would be corrected via the relationship found in Equation (1).

$$E_v = P_w - \Delta P\ Q_n \qquad (1)$$

The following procedure steps were used during testing to determine the shear characteristics of a piece of equipment. A graphical output of this procedure is shown in Figure 2.

1.) Rheological tests were conducted on the Newtonian standard to determine viscosity at the test temperature.

2.) From trials with Newtonian standards, power number (PO) vs. Reynolds number (Re) relationships were defined using Equations (2) and (3).

$$PO = \left(\frac{E_V}{\rho \, N^3 D^4 L} \right) \tag{2}$$

$$RE = \left(\frac{D^2 \, N \, \rho}{\mu} \right) \tag{3}$$

3.) By linear regression an equation correlating (PO) and (Re) for the Newtonian material was obtained.

$$PO = K_p \, RE^{(-c)} \tag{4}$$

4.) Rheological testing on the non-Newtonian fluid was conducted to define the apparent viscosity vs. shear rate relationship (Equation 5.).

$$\eta_a = K \, \gamma^{\,(n-1)} \tag{5}$$

5.) With trial data on the non-Newtonian fluid, a power number (PO) was calculated for each test condition using Equation (2).

6.) Using each power number of non-Newtonian test data and Equation (4), RE was calculated for each non-Newtonian test condition.

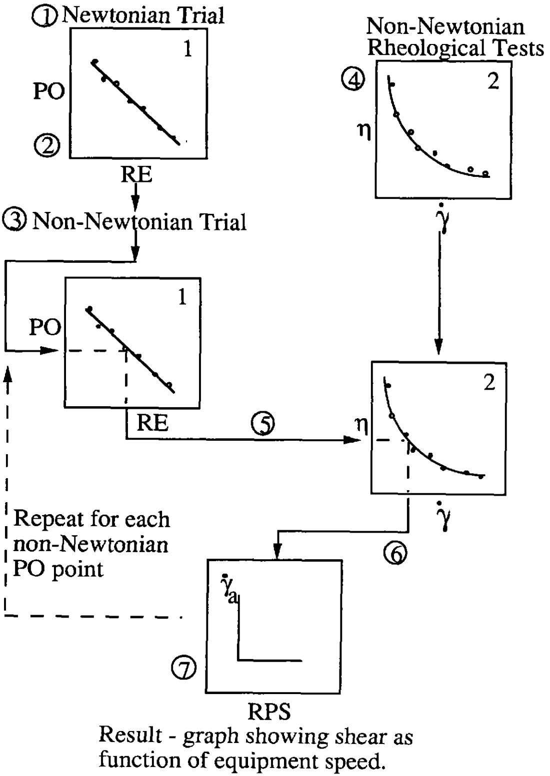

Figure 2.) Procedure flow diagram for determining shear.

7.) With the Reynolds number for the non-Newtonian material and using Equation (6) (from Equation 3), apparent viscosity was calculated for the fluid at each test condition.

$$\eta_a = \left(\frac{D^2 N \rho}{RE}\right) \tag{6}$$

8.) From each apparent viscosity (η_a) and the rheological equation for the non-Newtonian fluid, Equation (5), the corresponding average shear rate (γ_a) was calculated using Equation (7).

$$\gamma_a = \left(\frac{\eta_a}{K}\right)^{\left(\frac{1}{n-1}\right)} \tag{7}$$

9.) Correlation of the apparent average shear rate (γ_a) to equipment settings (RPS and material flowrate) was found for each test condition, and was used to develop a general relationship between average shear rate and equipment rotational speed.

This methodology for shear determination was applied to the scraped-surface heat exchanger used in the manufacture of margarine and tablespreads. The particular heat exchanger tested utilized three barrels in series to give a total surface area of 0.557 m^2 (6.0 ft^2). The Newtonian standard utilized was a low DE (dextrose equivalent) corn syrup with 10% water added. A time-independent non-Newtonian material, Xanthan gum, at 1% level was used in water solution. Rheology of both materials was tested using a Carri-Med controlled stress rheometer with cone and plate geometry. Flowrates of 0.07, 0.132, and 0.22 kg/s (9.7, 17.4, and 29.4 lb./min) were tested, along with rotational speeds from 1.7 to 7.5 revolutions per second (RPS). Including replicates, a total of 72 observations were made during the test procedure. Pressure drop and temperature change through the equipment were negligible during testing. (All testing was completed at room temperature (22°C), with the SSHE operating as a simple continuous mixer with no heating or cooling.)

The scraped surface heat exchanger used in the study had a constant shell diameter of 0.15716 m (0.516 ft) over a length of 0.50165 m (1.646 ft) for each barrel. The rotating dasher (shaft) had a diameter of 0.12758 m (0.419 ft). Geometry information for the scraped surface heat exchanger was similar for all barrels.

Four series of scraping blades were present on the dasher during testing. The rotational shear in the annular gap between the dasher and blades and the barrel wall is the primary shearing factor. Therefore, the scraping blades were neglected in the geometry term during analysis. It is difficult to express the presence of blades in the geometry term during calculations.

An analysis of the average shear in the secondary unit (whipper) used in this study was conducted in a manner similar to that used for average shear in the SSHE. Initial results from the experiment showed that the power consumption information was not precise enough for the proposed experimental analysis method. Therefore, complete testing of the secondary unit was not preformed, and a simple estimate was used for the relationship of shear rate to secondary unit rotational speed in the study.

B. Equipment Settings

1. Experimental Design

When considering the crystallization operations of margarine and tablespreads, experimental variables must be selected which are significant, independent, and controllable by available equipment. In this study, four equipment settings have been identified for study; surface area of heat exchanger (SA), rotational speed of the heat exchanger

(RPMS), rotational speed of the secondary unit (RPMW), and the overall process flowrate (FLOW).

a. Response Surface Methodology

Due to the number of variables and high cost of conducting trials with process systems, response surface methodology (RSM) techniques were utilized in determining an experimental design for this study. A RSM experimental design uses orthogonal relationships among parameters to isolate effects, while eliminating the need to test all possible combinations of variables (Box and Draper, 1987; Biles and Swain, 1980). These benefits allow for broad knowledge to be gained while drastically reducing number of trials, and cost. For these reasons, RSM is an important element in this study.

When doing a response surface experimental design, it is necessary to have a wide range of conditions available for each factor. Three of the variables, RPMS, FLOW, and RPMW can be manipulated continuously over a prescribed range, which allows for a large number of conditions. With the experimental constraint of equipment available, the variable of surface area was only available at two levels, 0.1858 and 0.3717 m^2 (2.0 and 4.0 ft^2). This restriction required that this variable be considered as a qualitative variable, which considerably complicated the experimental design. (The combination of quantitative and qualitative variables in a RSM is still a development field in statistics.) For use in response surface designs, parameter conditions must be converted to coded units, such that the center point is 0, and points above and below are +1, -1 etc. Use of coded units is important since it ensures that the design will be orthogonal. Converting to coded units is a simple matter for each condition by subtracting the center value and dividing by the increment between conditions. Table 1 contains the conversion table between coded units and equipment settings.

Table 1.) Conversion table to equipment settings from statistical coded units.

Equipment Setting	Coded Units -2	-1	0	+1	+2
SA m^2 $(ft)^2$		0.1858 (2)		0.3716 (4)	
RPMS rad/sec (rpm)	10.47 (100)	20.94 (200)	31.42 (300)	41.89 (400)	52.36 (500)
FLOW kg/sec (lb./min)	0.0379 (5.0)	0.06628 (8.75)	0.0947 (12.5)	0.1231 (16.25)	0.1515 (20.0)
RPMW rad/sec (rpm)	10.47 (100)	28.80 (275)	47.12 (450)	65.45 (625)	83.78 (800)

b. Statistical Design

Table 2 contains the statistical design developed for this study with the aid of statistical personnel at the Kraft Technology Center. Due to the difficulty in changing the levels of surface area, the design is blocked into 2 blocks where each block corresponds to a surface area. Since the cost of each trial is high, replications were not conducted on each condition, but were performed for the central portion of the design. The experimental design was utilized for each of the formulations studied, with the treatments randomized for each application. The design allows for analysis of linear effects and linear interactions of the four factors. Quadratic effects are also distinguished through the design for the three quantitative terms. A total of thirteen different factors are available for analysis through use of this design. A randomized version of Table 3 was the testing plan used in the study.

2. Materials

The experimental treatments have been conducted on three different margarine and tablespread emulsion types: 80, 50, and 40% oil formulations. Hydrogenated soybean oil was utilized in all three formulations in the study. The difference between emulsions is more than just the oil level, stabilizers and other ingredients must be used for stability. Although differences in ingredients may have some impact on material attributes, these factors were not considered. In this study, the only formulation distinction to be considered will be oil level, with no mention or consideration of other ingredients, since formulas used in this study are proprietary.

Table 2.) Response surface design in coded units for margarine and tablespread crystallization operations.

Treatment	Surface Area	RPMS	Flowrate	RPMW
1	-1	-1	-1	-1
2	-1	-1	-1	+1
3	-1	-1	+1	-1
4	-1	-1	+1	+1
5	-1	+1	-1	-1
6	-1	+1	-1	+1
7	-1	+1	+1	-1
8	-1	+1	+1	+1
9	-1	0	0	0
10	-1	0	0	0
11	+1	-2	0	0
12	+1	+2	0	0
13	+1	0	-2	0
14	+1	0	+2	0
15	+1	0	0	-2
16	+1	0	0	+2
17	+1	0	0	0
18	+1	0	0	0
19	+1	0	0	0
20	+1	0	0	0

Table 3.) Experimental plan based on response surface design in actual equipment settings.

Treatment	SA m^2 (ft^2)	RPMS rad/sec (rpm)	FLOW kg/s (lb/min)	RPMW rad/sec (rpm)
1	0.186 (2)	20.94 (200)	0.066 (8.75)	28.80 (275)
2	0.186 (2)	20.94 (200)	0.066 (8.75)	65.45 (625)
3	0.186 (2)	20.94 (200)	0.123 (16.25)	28.80 (275)
4	0.186 (2)	20.94 (200)	0.123 (16.25)	65.45 (625)
5	0.186 (2)	41.89 (400)	0.066 (8.75)	28.80 (275)
6	0.186 (2)	41.89 (400)	0.066 (8.75)	65.45 (625)
7	0.186 (2)	41.89 (400)	0.123 (16.25)	28.80 (275)
8	0.186 (2)	41.89 (400)	0.123 (16.25)	65.45 (625)
9	0.186 (2)	31.42 (300)	0.095 (12.50)	47.12 (450)
10	0.186 (2)	31.42 (300)	0.095 (12.50)	47.12 (450)
11	0.372 (4)	10.47 (100)	0.095 (12.50)	47.12 (450)
12	0.372 (4)	52.36 (500)	0.095 (12.50)	47.12 (450)
13	0.372 (4)	31.42 (300)	0.038 (5.00)	47.12 (450)
14	0.372 (4)	31.42 (300)	0.152 (20.00)	47.12 (450)
15	0.372 (4)	31.42 (300)	0.095 (12.50)	10.47 (100)
16	0.372 (4)	31.42 (300)	0.095 (12.50)	47.12 (800)
17	0.372 (4)	31.42 (300)	0.095 (12.50)	47.12 (450)
18	0.372 (4)	31.42 (300)	0.095 (12.50)	47.12 (450)
19	0.372 (4)	31.42 (300)	0.095 (12.50)	47.12 (450)
20	0.372 (4)	31.42 (300)	0.095 (12.50)	47.12 (450)

3. Process Equipment and Methodology

The experimentation for this study has taken place at the Kraft Technology center of Kraft General Foods, Inc. located in Glenview, Illinois. Pilot-plant scale equipment, similar to production scale processing equipment, was utilized and allowed greater freedom in conducting experiments.

A diagram representing the processing operations is depicted in Figure 3. Emulsions were manually formulated and were created in a 45 gallon jacketed churn manufactured by Walker, Inc. The emulsion was pumped via a lobed positive-displacement pump (Waukesha Model 15) through a scraped-surface heat-exchanger (APV Crepaco, Inc.) where it was cooled through a jacketed ammonia expansion system. The cooled emulsion was then piped to an agitated holding unit (Cherry-Burrel Anco/Votator Model) where it was sheared (worked) during crystallization. At the exit of the working unit the cooled emulsion was either filled into containers, or reheated and added to the batch tank in a manner similar to typical manufacturing procedures.

During testing, when conditions for a particular treatment were set, the process was allowed to stabilize, then test material was filled into 8 oz. tub containers and moved to a large cooler (7°C/45°F). Monitoring of the process was aided through the use of multiple thermocouples and pressure gauges added to the process setup.

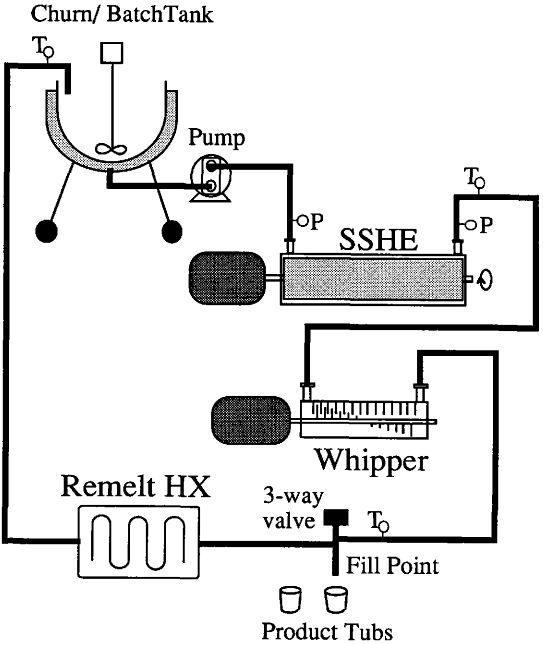

Figure 3.) Equipment set-up for equipment settings experiment.

4. Product Evaluation

a. Dynamic Testing

Assessment of rheological properties for the margarine and tablespread products was completed through use of a Rheometrics Mechanical Spectrometer (RMS) model RMS 605, which measures dynamic rheological information. Parallel plate geometry was utilized for testing, with the plates serrated to prevent slip at plate surfaces. The serrated plates had a radius of 25 mm, and a gap of 2 mm. A frequency sweep test was conducted over three decades, from 0.1 to 100 radians per second. The amount of strain for testing was preset at the 1% level. These conditions correspond to a low shear rate, which is low enough not to disturb the crystal structure of the sample. The RMS unit is equipped with a nitrogen cooling system, which allows sample and chamber to be accurately maintained at the test temperature of 7°C. (Sample test temperature was chosen to correspond to a typical temperature which consumers use tablespread products, refrigerator temperature.) The RMS testing procedure entails considerable time and effort, and as a result only one sample for each test treatment was measured.

Due to the nature of margarine/tablespread products, the storage modulus (G') and loss modulus (G") displayed consistent values over the range of frequencies tested. The values of G', G", and complex viscosity (η^*) were recorded at a frequency of one radian per second. The complex viscosity is the only factor considered as a dependant variable, since the concept of complex viscosity is most straightforward and is a function of G' and G". The units of complex viscosity are recorded in units of 1000 poise.

b. Cone Penetrometer

The assessment of texture attributes was completed using the industry standard of a cone penetration test. The cone penetrometer utilized in this study was manufactured by American Scientific (model number P2530-1), with a cone that weighs 43 grams, having an angle of 40° degrees. The penetrometer and samples were placed in a large walk-in cooler held at 7°C, and allowed sufficient time to reach equilibrium before testing.

A flat sample surface is required for testing, and the sample is prepared by scraping the surface of the 8 oz. tub so that it is level. With the tub below the cone, the cone was lowered to the surface and distance recorded. The cone was then moved vertically 10 mm above the surface and released from rest. The penetration depth was then measured approximately 5 seconds after release. The distances were subtracted and recorded in units of tenths of millimeters. Four measurements were recorded for each experimental condition, and results averaged.

c. Thermal Properties

Thermal properties were measured through use of a differential scanning calorimeter (DSC) manufactured by Perkin-Elmer, model DSC-4. Samples were maintained at 7°C and loaded into sample pans, where they were weighed and loaded into the calorimeter. The calorimeter was programmed to start at 0°C and add heat at a constant rate of heat (20°C per minute) to a final temperature of 60°C. A high rate of heating was chosen in an attempt to simulate melting characteristics of the material in a human mouth.

A review of results from the 80% formulation showed no significant differences in test results among even the extreme experimental conditions. Analysis of extreme condition samples from the other formulations resulted in similar results. There was no significant difference between samples of the same formulation, although the magnitudes were different between formulations. In view of these results, additional testing was discontinued, and no results are reported for thermal properties in this study.

5. Analysis of Data

The attribute information for each treatment was included in a data file with the equipment conditions in the original, coded unit form. Statistical analysis was conducted using procedures from a Statistical Analysis System (SAS) package operating on an IBM 3090-200E mainframe computer. Regression was conducted using the PROC REG procedure for the dependant cone penetration and complex viscosity terms. (The PROC RSREG option, which is available in SAS for response surfaces, was not used since it assumes a response surface of only quantitative factors). Primary, linear interactions, and quadratic effects were utilized as regressors. The linear interaction and quadratic terms were defined and calculated in the data step prior to regression. In addition to typical regression output, variance inflation factors (VIF) were calculated to confirm the orthogonal nature of the experiment.

Results of the regression procedures were tabulated and plots produced of observed vs. predicted to confirm the fit of the model. In addition, a plot of residuals against observed output was produced as a check of the model.

C. Engineering Parameters

Through literature review, discussion with research engineers, and personal experience, five engineering parameters were determined to be significant for a process analysis of margarine and tablespread crystallization operations. The five primary factors are: scraped-surface heat exchanger (SSHE) cooling rate, SSHE peak shear, SSHE shear history, secondary unit (SU) peak shear, and SU shear history. These factors are functions of the operating conditions of the equipment, however, they are independent of the type or size of equipment being used. The determination of this generic information for the study will allow information to be more applicable to a wide range of tablespread applications, at the bench, pilot, and plant scales.

1. Parameter Assessment

a. SSHE - Cooling Rate

For oil crystallization, the cooling rate has been identified by researchers as an important factor in formation of crystal networks and particular types of crystals (Joyner, 1953; Bolanowski, 1965). The cooling rate of the emulsion material was a function of the change in temperature through the unit and the amount of time the material is contained in the SSHE. The temperature change in cooling the emulsion for the study was held constant at 27.8°C (37.8°C initial temperature, 10°C outlet temperature). The residence time that the material was in the SSHE is a function of the geometry and the flowrate used in the test, and as a result was the primary change in the cooling rate. The overall average cooling rate was used as an approximation for the entire cooling process.

$$\left(\frac{dT}{dt}\right) = \frac{\text{Change in Temperature}}{\text{Time to Change Temp.}} = \frac{\Delta T}{t_{sshe}} \tag{8}$$

b. SSHE - Shear History

Shear history is a dimensionless quantity which represents the interaction of shear rate over time for a material in an operation (Equation 9). The average shear throughout the SSHE and the residence time of the material determine the shear history.

$$\Phi_{sshe} = \int_0^t \gamma \, dt \tag{9}$$

A gross approximation of the SSHE shear history was to compute the Newtonian simple shear in the SSHE annulus and multiple it by the average residence time (Equation 10).

$$\Phi_{sshe} \approx \gamma_{a\text{-}sshe} * t_{sshe} \tag{10}$$

The determination of average shear in the SSHE was the subject of considerable investigation in this study, and is discussed in detail in the shear determination sections. The residence time in the SSHE is a function of the geometry and the process flowrate, and is the same as the residence time utilized for cooling rate.

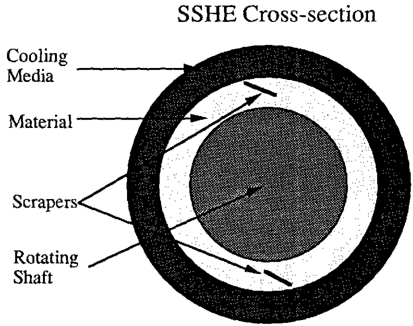

Figure 4.) Cross-section of scraped-surface heat exchanger.

c. SSHE Peak Shear Rate

Peak shear in the SSHE unit was estimated through Newtonian simplified flow and geometry calculations. The position where the material flows through the smallest gap is considered to be the point of highest (peak) shear. In the SSHE unit the smallest gap is located at the junction where the blades on the shaft meet the center portion (see Figure 4). At this location there is a 0.0064 m (0.25 inch) gap which all material must flow through as the shaft rotates. The shear in this gap was calculated using the assumption of slit flow, since the material flowed through a fixed, rectangular gap. Because the gap was small, and accurate rheological properties are not known, the Newtonian relationship for slit flow properties was utilized.

$$\gamma_{p\text{-}sshe} = \left(\frac{6*Q}{h^2*w}\right) \tag{11}$$

The flowrate through the gap (Q) was determined from the rotational speed and volume of material in the SSHE. The height (h) and width (w) define the geometric characteristics of the slit, and correspond to the small gap, and the length of the shaft. For a particular set of geometry, only the rotational speed of the SSHE affects the peak shear in the operation.

d. Secondary Unit Shear History

Shear history in the secondary unit (Figure 5) was determined to be similar to that in a SSHE, a function of the process average shear and the residence time in the unit. The residence time is calculated from the flowrate and the volume of the secondary unit.

$$\Phi_{SU} \approx \gamma_{a\text{-}su} * t_{su} \tag{12}$$

The average shear in the secondary unit was estimated from the midpoint in the radius (r_a) of the secondary unit agitator. The velocity at the point was calculated from the rotational speed (N) and the radius of interest. The clearance between the agitator and the pins from the vessel wall served as the gap (g) over which the shear was estimated, assuming parallel plate flow.

$$\gamma_{a\text{-}su} = \left(\frac{2*\pi*r_a*N}{g}\right) \tag{13}$$

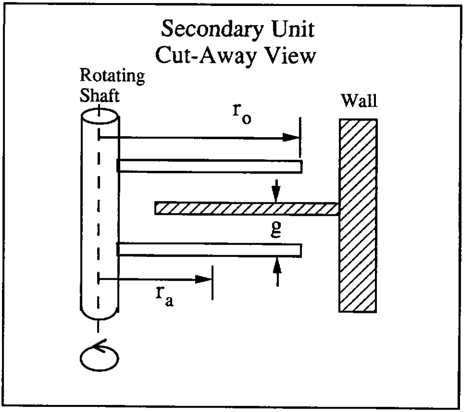

Figure 5.) Cut-away view of secondary unit showing critical dimensions.

e. Secondary Unit Peak Shear

The peak shear rate of the secondary unit was measured in the same manner as the average shear. The peak shear is evaluated at the largest radius of the agitator (r_o), which has the highest velocity relative to the fluid (Figure 5). The gap over which the shear is measured is the same as that used for estimation of the average shear, since the geometry is symmetric.

$$\gamma_{p\text{-}su} = \left(\frac{2*\pi*r_o*N}{g}\right) \tag{14}$$

2. Engineering Parameters Methodology

Due to the strong interdependence of engineering parameters, it is difficult to develop a statistical design to isolate and determine effects of the engineering factors. Since an experimental procedure could not be developed for efficiently investigating the effects of engineering parameters, simulation models were employed which were based on the equipment parameters. The key problem was that the engineering parameters could not be fixed or as easily controlled as the equipment parameters. Therefore, engineering parameters were developed as functions of the equipment conditions.

Using SAS programmed in a manner similar to FORTRAN, simulation models for each formulation were created based on the results from the equipment models. A wide range of equipment conditions were then generated over the typical operating range of the equipment. From these generated conditions, values of cone penetration and complex viscosity were estimated. In addition, estimated engineering parameters are calculated for each set of generated equipment conditions.

Results of the simulation were then used as a data base for statistical analysis of engineering parameters. A regression procedure on each simulated data set for each formulation was conducted. Only the primary five factors were used in analysis since interactions cause considerable difficulty due to interdependence (also known as multicollinearity).

CHAPTER IV

RESULTS

Research was conducted in three areas; determination of shear, equipment parameter effects, and engineering parameter effects. These different aspects of research allow for a more thorough processing and engineering understanding of the margarine and tablespread crystallization operations. Measurement of product attributes was made through use of cone pentration and complex viscosity values.

A. Shear Determination

The following are results of applying the shear determination procedure to a scraped-surface heat exchanger (SSHE) used for production of margarine and tablespreads. Results are presented in the same step-by-step format as described on pages 12 to 16.

1.) Rheological testing on corn syrup, as the Newtonian standard, yielded a Newtonian viscosity of 1.9 pa-s.

2.) SSHE testing was conducted with the Newtonian material, which determined power consumption information as a result of flowrate and rotational speed. The power and Reynolds numbers were calculated using observed power, flowrate, rotational speed and geometry information. The relationship between power and Reynolds numbers is graphically displayed in Figure 6.

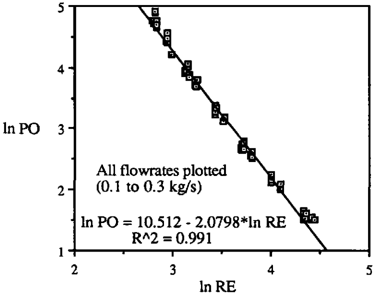

Figure 6.) Power vs. Reynolds number relationship for Newtonian fluid in the scraped-surface heat exchanger.

3.) From the relationship between power and Reynolds numbers the mathematical relationship among these factors was determined and defined by Equation (15).

$$PO = 36754 * RE^{(-2.08)} \tag{15}$$

4.) Rheological testing on the 1% Xanthan gum solution as the non-Newtonian fluid resulted in the relationship shown in Equation (16).

$$\eta_a = 46.01 * \gamma^{(-.7636)} \tag{16}$$

5.) Testing was conducted with the non-Newtonian fluid, the power consumption, rotational speed, and flowrate were recorded. From this information, the power number was determined for each non-Newtonian test condition.

6.) From each non-Newtonian power number, a corresponding Reynolds number was found using Equation (17), which was derived from Equation (15).

$$RE = \left(\frac{PO}{36754}\right)^{\left(\frac{1}{2.08}\right)} \tag{17}$$

7.) The apparent viscosity was computed from substituting Equation (17) into Equation (18) for each condition.

$$\eta_a = \frac{D^2 N \rho}{RE} \tag{18}$$

8.) The average shear rate was computed by substituting the apparent viscosity into Equation (19).

$$\gamma_a = \left(\frac{\eta_a}{46.01}\right)^{\left(\frac{1}{-0.7636}\right)} \tag{19}$$

9.) Average shear rates were computed for each rotational speed and flowrate, and are plotted in Figure 7.

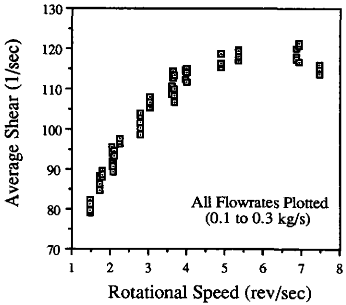

Figure 7.) Average shear rate vs. RPS for scraped-surface heat exchanger.

As expected, flowrate showed negligible effect on the average shear rate in the SSHE. With other forms of process equipment and geometry, flowrate may have significance. Mixing methods typically calculate shear as some constant multiplied by the rotational speed. From Figure 7, a strong linear dependence is displayed over low rotational speeds. At high speeds, flow may have become turbulent or significant backmixing may have taken place.

As a reality check, theoretical calculations of shear rate based on couette flow of the SSHE were made using Equation (20), assuming Newtonian flow conditions. This relationship is a function of the angular velocity (Ω) and the shell (r_o) and shaft radius (r_i).

$$\gamma = 2*\Omega*\left(\frac{(r_o/r_i)^2}{(r_o/r_i)^2-1}\right) \qquad (20)$$

Equation (20) is plotted in Figure 8, and over predicts shear, with increasing error for higher rotational speeds.

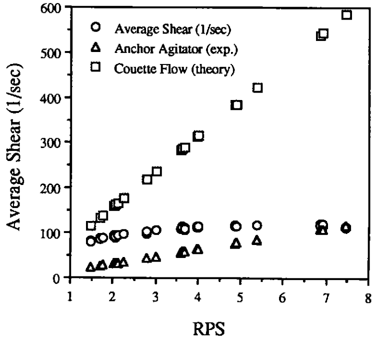

Figure 8.) Comparison of shear rate calculations from three methods.

Shear rate in a scraped surface heat exchanger was also estimated through comparison of empirical data available for similar equipment. An anchor agitator was selected for comparison due to close tolerances between agitator and wall, and geometric symmetry. The relationship between shear rate and rotational speed was reported from experimentation to have a value of 16; sixteen times the rotational speed gives the shear rate (Cheremisinoff and Gupta, 1983). A comparison of the anchor agitator estimation for shear rate to experimental findings can be found in Figure 8.

The average shear rate determined in the study falls between the levels of extremes from couette flow and anchor agitator comparisons. At low levels of rotational speed, the slope from experimental data was parallel to that of the anchor agitator. The shear predicted by couette flow starts at a level near that found experimentally, but proceeds at a much higher slope. Near the highest rotational speed of the SSHE, the average shear rate found experimentally levels off, and exhibits non-linear behavior which is not predicted through comparison with other shear rate estimations. The presence of the high rotational speed shear rate characteristics is an important one, since it points out a serious defect in use of theoretical methods for estimating shear in process equipment.

B. Equipment Settings

Experiments were conducted using equipment settings of SSHE RPM, flowrate, cooling rate, and secondary unit RPM as process variables. Product attributes were measured through use of cone penetration, and complex viscosity tests.

Analysis of equipment testing has yielded insight on the margarine and tablespread crystallization operations. Regression procedures were used to develop meaningful models of cone penetration and complex viscosity attributes as a function of equipment settings.

The coefficient of determination (R^2) is a commonly accepted measure of statistical fit for regression models, and was considered in analysis of equipment testing. The R^2 value is dependent on the degrees of freedom in an analysis and becomes distorted when the number of samples is small and a large number of regressors are used. The use of an adjusted R^2 term, which takes into account the number of regressors and treatments, is an appropriate measure of the model fit to the data, and was utilized in analysis of equipment settings effects.

Due to an error in conducting the experiment with the 80% oil formulation, one of the test conditions was excluded, and instead another condition inadvertently repeated. Because of this error, the power of the response surface methodology was significantly reduced, but results are still meaningful. Actual results from tests on equipment settings are found in appendix A. The statistical analysis for cone pentration and complex viscosity as a function of equipment settings is found in Appendix B.

Graphical display of statistical models generated can be found in Appendix C. Results were extrapolated into a continuous grid and smoothed to allow for clear assessment of results as a function of two factors. The graphical representation of attributes vs. process variables allows development of an operating curve for a particular product and equipment.

1. Cone Penetration

Models were developed based on cone penetration and shown to have a high degree of correlation to collected data. Models of all three formulations have adjusted R^2 values in the 0.9 range, which indicates a strong relationship of the model to the data. (Full statistical analysis output for cone penetration and complex viscosity for all formulations can be found in Appendix B.)

Table 4 displays regression coefficients for the factors used in analysis. The regression coefficients indicate the direction and magnitude that the regressors affect the dependant properties in the statistical model. Since the regression was carried out with coded settings, the magnitude of each coefficient is a relative indicator of the significance for that factor in the model. The addition of coefficients, multiplied by process conditions, represents the resulting attributes of a processing condition. All coefficients have been shown regardless of significance, since the value of the coefficient is important when considering the broad scope of the problem. Coefficients that are insignificant at the 0.2 probability level are noted. Analysis with only significant factors will not change parameter estimates since each regressor was isolated due to the orthogonal nature of the experimental design.

Table 4.) Regression coefficients for cone penetration based on coded units of equipment settings.

Cone Regression Coefficients	Oil Formulation 80% Oil	50% Oil	40% Oil
	ADJ. - R^2 0.9013	ADJ. - R^2 0.9046	ADJ. - R^2 0.8868
Intercept	126.23	174.08	211.64
SA	11.932	10.505	15.365
RPMS	5.316	8.106	12.125
FLOW	-19.978	-20.031	-21.038
RPMW	0.913*	2.331*	0.088*
SA*RPMS	-0.816*	-1.531*	-6.125
SA*FLOW	-3.072*	7.206	8.713
SA*RPMW	2.012*	4.844	0.738*
RPMS*RPMW	-0.600*	0.988*	1.925*
FLOW*RPMW	-1.475*	2.263*	6.925
FLOW*RPMS	-6.407	-5.888	-2.825*
RPMS^2	0.440*	-0.071*	-1.368*
RPMW^2	0.553*	2.490	1.719*
FLOW^2	7.365	-2.760	1.469*

*Insignificant at 0.2 probability level

The primary variables of SA, RPMS, and FLOW were highly significant across all formulations. The other primary factor was RPMW, which contributed slightly to the model for the 50% oil case, while being insignificant in the models for other formulations.

As the surface area increased, contribution to the statistical model also increased, indicating that for large surface areas the product will be softer. Since the inlet and outlet temperatures were held constant, the factor of surface area only affected the residence time (due to increased volume) of the emulsion within the SSHE unit. Softening from increased SA was likely due to individual crystal growth, rather than formation of a tightly linked network of small crystals. The individual crystal growth was the result of slow cooling and/or excessive agitation, which takes place with increased surface area.

When the rotational speed of the scraped-surface heat exchanger (RPMS) was increased, the material became softer. This effect was significant for the 80% oil formulation, and became increasingly important through the 50%, to the 40% formulation where changes in RPMS strongly affected the texture. High rotational speeds in the scraped-surface heat exchanger result in increased heat transfer rate and raises the amount of shear on the emulsion. In the low oil formulations the shear may have changed the emulsion characteristics by changing the droplet size of the discontinuous phase, affecting rheological properties.

By far the most significant variable in the developed models of equipment settings was the process flowrate (FLOW). The contribution of this factor is nearly uniform across the three formulations studied. Increase in the flowrate of the emulsion through the system resulted in a drastic hardening of the resulting margarine/tablespread. Changes in the flowrate had a direct effect on the residence time of the material in the equipment, which in turn directly affected cooling rate. Increased hardness of the material at high flowrates may have resulted in more crystallization developing once the material was placed in the container, rather than in the process. When the material crystallizes in the container it is under static conditions, which promotes the growth of uniform, small crystals which have a high degree of networking. For low flowrates, more crystallization takes place within the process where agitation/shear does not allow for networking, and instead individual crystals develop.

The most surprising result of the study was the insignificance of the rotational speed of the secondary unit (RPMW). For the 40 and 80% formulations the variable was insignificant, while the 50% case was slightly significant. Since studies without use of the secondary unit were not conducted, actual contribution of this operation is difficult to assess.

The interaction terms in the cone penetration model are difficult to interpret due to significant differences in contribution and even direction (sign) across the three formulations. In addition, these terms are challenging to explain, since many interaction cases mean little from an engineering standpoint due to multiplication of factors with dissimilar units.

In the 80% model the most significant interaction was between the FLOW and RPMS terms. This term was a major contributor to this model, with significance even greater than the RPMS factor alone. This term was also an important element in the 50% model, but less meaningful in the 40% model. In all models the coefficient was negative, indicating that for increased FLOW or RPMS resulting product was harder. The interaction of FLOW and RPMS is an indicator of the total amount of shear/agitation which takes place on the material in the SSHE.

In both the 50 and 40% models the strongest interaction factor was between SA and FLOW. Since the primary factors in this interaction are highly significant, it is not surprising that some relationship could be found between them. The interaction is an indicator of crystallization due to changes in the rate of cooling, where SA and FLOW were controlling factors in the study. In addition,with the low oil formulation levels the SA*FLOW interaction may be indicating crystallization of the material within the SSHE.

The significant RPMW interactions, which relate to the secondary unit, are important since the primary variable lacked magnitude. With the 50% formulation model the interaction of SA and RPMW was relatively strong. This interaction is not of the same weight with the other models. The FLOW and RPMW interaction was significant in the 40% model, but not present in the other models. The RPMW*FLOW interaction is important since it is an indicator of the total amount of shear/agitation that takes place in the secondary unit. The secondary unit serves to form discrete crystals, and to distribute the heat of crystallization uniformly throughout the material. At the 40% formulation level nearly all crystallization takes place within the secondary unit.

The quadratic terms used in modeling the cone penetration values were for the most part not a strong component. The only significant squared term was for the FLOW in the 80% formulation model, where the contribution was strong. Since the term was positive, it negates from the strong effects of the primary term which had an opposite sign. For low to normal flow situations the linear model predominates, but at higher rates of flow the higher order term takes over and causes increases in FLOW to yield softer products. Very high flowrates may initiate a change in the flow pattern of the material through the operations, and in some manner encourage growth of individual crystals, resulting in softer products for the 80% formulation level.

2. Complex Viscosity

Analysis of data for complex viscosity attributes from equipment settings, has yielded results quite similar to those found from cone penetration values. The range of model correlations is much broader, with adjusted - R^2 values ranging from a relatively low 0.83 to a strong 0.97, as shown in Table 5. The 80% model for complex viscosity has the

Table 5.) Prediction model for complex viscosity (η*) based on coded units of equipment settings.

η* Regression Coefficients	Oil Formulation 80% Oil	50% Oil	40% Oil
	ADJ. - R^2 0.8266	ADJ. - R^2 0.9302	ADJ. - R^2 0.9694
Intercept	11076.4	5793.41	2350.59
SA	-2242.65	-781.60	-743.90
RPMS	-874.00	-625.13	-627.81
FLOW	3658.38	2128.13	772.44
RPMW	129.62*	-135.75*	-117.19
SA*RPMS	388.25*	18.13*	399.56
SA*FLOW	-1291.13	-93.63*	-582.69
SA*RPMW	-850.62	-413.75	91.69
RPMS*RPMW	20.49*	-371.00	-117.89*
FLOW*RPMW	-47.74*	422.50	-140.38
FLOW*RPMS	674.76*	16.75*	-660.34
RPMS^2	-530.56*	-173.05*	99.54
RPMW^2	193.44*	-197.30	26.67*
FLOW^2	399.07*	461.95	69.55*

* Insignificant at 0.2 probability level

0.83 R^2, this low value is due in part to the experimental defect mentioned previously. The other two models were quite strong, significantly more so than those found for cone penetration values. This is not surprising, since complex viscosity is a more comprehensive measurement of rheological properties than the cone penetration measurement.

The process flowrate (FLOW) was the single most important variable in models of complex viscosity. The coefficient for this factor was positive, indicating that for increases in FLOW, the product will have a higher viscosity. High levels of flowrate result in limited crystallization in the process, and instead oil crystallizes statically in the container. Static crystallization results in a high degree of networking between crystals, yielding higher viscosity (increased yield stress).The importance of flowrate decreases across the formulations, at the 40% oil level the factor of FLOW is not distinctly higher than other important terms in the model. The process flowrate (FLOW) was the single most important variable in models of complex viscosity. The coefficient for this factor was positive, indicating that for increases in FLOW, the product will have a higher viscosity. High levels of flowrate result in limited crystallization in the process, and instead oil crystallizes statically in the container. Static crystallization results in a high degree of networking between crystals, yielding higher viscosity (increased yield stress).The importance of flowrate decreases across the formulations, at the 40% oil level the factor of FLOW is not distinctly higher than other important terms in the model.

Heat exchanger surface area (SA) was a significant negative factor across all models. At all oil levels the SA was the second most important factor in the models, and in the 80% oil level model was a very strong contributor. The SA has a large effect since it relates to both crystallization kinetics and residence time within the SSHE. With increased surface area the slow cooling rate may result in less uniform crystallization.

Rotational speed of the heat exchanger shaft (RPMS) has shown to be an important factor for complex viscosity in all three formulations. The coefficient of RPMS is negative, and was relatively uniform for the formulations. The rotational speed relates directly to the amount of agitation the material receives in the SSHE. Change in agitation affects the highest shear which the material receives in the unit and also affects the heat transfer coefficient. These two important elements could influence the product in numerous ways.

The fourth primary factor in the modeling was the rotational speed of the secondary unit (RPMW). The coefficient of RPMW was insignificant in the 80 and 50% models, and had little impact on the lowest oil model. The results for RPMW relating to complex viscosity agree with models based on cone penetration values, where it was also insignificant.

Interaction terms in the complex viscosity models are an area where differences were found when compared to the cone penetration models. The interaction of heat exchanger surface area and process flowrate (SA*FLOW) was an important element in models for complex viscosity. These coefficients were negative, and in the 80% oil case a strong factor. The interaction was also important in the 40%, but was suspiciously insignificant in the 50% oil formulation. Surface area and flow rate control the total amount of residence time which the material resides in the heat exchanger operation. The residence time is an important element in determining the cooling rate and total amount of shear which takes place on the equipment.

Interactions which take place involving the secondary unit are important since the primary factor of RPMW was not significant. The SA*RPMW interaction is significant for all three formulations. The importance of the factor decreases across formulations from a large value in the 80% model, and in all cases has a negative impact on the complex viscosity. An understanding of the importance is difficult to obtain, since the factor involves aspects from two different units. The linkage was a combination of the crystallization kinetics (SA), and the shear in the secondary unit

(RPMW). As the cooling rate from SA changes, the importance of shear on the crystallization in the secondary unit also changes.

The relationship of FLOW*RPMS was found to be successful in the 40% oil formulation, while being insignificant in the other models. The relationship between flowrate and heat exchanger rotational speed is important since it controls the total amount of shear on the material in that operation. An increase in the interaction term results in lower viscosity material in the 40% formulation, possibly due to changes in the emulsion state, rather than affecting crystallization.

For the most part the primary terms squared did not show significance in the complex viscosity models. The only exception is for the 50% oil case of FLOW squared, which had a strong impact. In the other models for this factor, the coefficients are not even close or significant. Since flowrate is the predominate factor in all models, it is not surprising that squared term would be significant. The squared term accounts for any non-linearity in the flow, and effects the product through the same mechanisms as the linear term.

C. Engineering Parameters

The succession from equipment settings to engineering parameters is a natural one from a process engineering standpoint. The information developed from equipment settings was dependant on the actual equipment used in the study, whereas engineering parameters allow for transfer of the knowledge to other types and scales of processing equipment. In addition, concepts of shear and cooling which are discussed when explaining results from equipment settings relate directly to engineering parameters.

Five engineering parameters were utilized in analysis of product effects; heat exchanger cooling rate (DT), heat exchanger shear history (HXSH), heat exchanger peak shear (HXPS), secondary unit shear history (SUSH), and secondary unit peak shear (SUPS). The statistical analysis on the effect of engineering parameters on attributes has resulted in strong models for cone penetration and complex viscosity for all formulations. These models are highly correlated, with coefficients of determination (R^2) values from 0.82 to 0.94. An important element in models from engineering parameters was the absence of interdependence among the factors. This indicates that the factors were appropriate, and each related to the data uniquely.

Results for models developed based on the engineering parameters are presented in tables 6 and 8. Unlike the previously described equipment settings models, the factors for engineering parameters are not in coded units. As a result, interpretation of data is challenging since the factors have a wide range of magnitudes. All engineering parameters were found to be highly significant, except for the three indicated coefficients. For determination of the relative importance of factors, the Type II SS (sum of squares) has been displayed in Tables 7 and 9, corresponding to the cone penetration and complex viscosity models. The Type II SS are an indicator of the contribution of each factor to the overall model, and are independent of magnitude for the factor. The full SAS analysis, including simulation models, can be found in Appendix D.

As the cooling rate (DT) was increased, in both the cone penetration and complex viscosity models, the product became harder (more viscous). This factor has a strong influence on the models, with the exception of the 80% formulation in the cone penetration model where the factor was insignificant. The rate of cooling shows progressive importance as the oil level decreases, with no significance at the highest oil level. The cooling rate is an important element in oil crystallization, and this importance may be deceptive when applied across formulations, especially with low oil levels. Another approach might have been to correct the cooling rate for the amount of oil in the formulation.

Table 6.) Prediction model for cone penetrometer value based on engineering parameters.

Cone Regression Coefficients	Oil Formulation 80% Oil	50% Oil	40% Oil
	$R^2 = 0.9437$	$R^2 = 0.8887$	$R^2 = 0.9039$
Intercept	80.93	197.24	223.02
DT	-2.017*	-64.7693	-79.1788
HXSH	0.006588	-0.00193	-0.00065
HXPS	0.002671	0.00617	0.00884
SUSH	0.000715	0.00083	0.00047
SUPS	-0.070059	-0.07083	-0.05191

* Not significant at the 0.10 probability level

Table 7.) Type II SS of engineering parameters for cone penetration prediction model.

Cone Regression Type II SS	Oil Formulation 80% Oil	50% Oil	40% Oil
	$R^2 = 0.9437$	$R^2 = 0.8887$	$R^2 = 0.9039$
Intercept	15861	94213	131497
DT	17.5	18016	25149
HXSH	11352	975	117
HXPS	4028	21465	44073
SUSH	11379	15304	5244
SUPS	6609	6755	3629

Table 8.) Prediction model for complex viscosity (η^*) based on engineering parameters.

η^* Regression Coefficients	Oil Formulation 80% Oil	50% Oil	40% Oil
	$R^2 = 0.9265$	$R^2 = 0.9144$	$R^2 = 0.8118$
Intercept	4643.29	5936.84	298.84
DT	12434.00	3617.77	4937.83
HXSH	0.31190	0.01168*	0.190559
HXPS	-0.68297	-0.45155	-0.485898
SUSH	-0.14381	-0.12396	-0.011146
SUPS	16.66113	12.33585	0.291786*

* Not significant at the 0.10 probability level

Table 9.) Type II SS of engineering parameters for complex viscosity prediction model.

η^* Regression Type II SS	Oil Formulation 80% Oil	50% Oil	40% Oil
	$R^2 = 0.9265$	$R^2 = 0.9144$	$R^2 = 0.8118$
Intercept	52211684	85354420	216274
DT	663961659	56208617	97808401
HXSH	25444294	35656	10167691
HXPS	263329850	115108323	133285206
SUSH	460734904	342327261	2962759
SUPS	373813067	204919621	114651

The shear history in the heat exchanger (HXSH) and secondary unit (SUSH) maintained relatively consistent trends across the complex viscosity and cone penetration models. At the 80% oil formulation level, HXSH and SUSH are the primary factors. The importance of these factors decreases through the 50% level to the 40% level where there is little or no effect. The high oil content formulation may be more sensitive to shear history since it has more crystal networking taking place throughout the processing. At lower oil levels the crystallization was less important, and changes in the shear history may not significantly affect the networking during crystallization.

The importance of peak shear was nearly opposite that of shear history in the heat exchanger across the formulations. The HXPS factor was a very strong factor in the 40% models, but had little significance in the 80% model, with the 50% formulation at intermediate levels. The peak shear in the heat exchanger was significantly higher than the average shear rate in the unit, which was used in calculation of shear history. The large difference in shear is the key to understanding why the HXPS factor was important in the low oil content formulations. The heat exchanger peak shear was probably not affecting the crystallization, rather it was changing the emulsion nature of the material. At high shear in materials with a low continuous phase (low oil content), the shear is decreasing the droplet size (discontinuous phase) in the emulsion and affecting the rheological characteristics.

The peak shear in the secondary unit (SUPS) behaves in a similar manner to the shear history effects. At the 80% oil formulation level the SUPS factor was relatively important, while at the lowest oil level the factor was insignificant. The crystal networking that takes place in the secondary unit is much more important for high oil contents, and the presence of agitation (shear) has a strong effect. The agitation disrupts the networking of oil crystals, and promotes growth of individual crystals. The SUPS did not affect the emulsion rheological characteristics for the low oil formulation (as in the HXPS), since the difference in peak shear and average shear in the secondary unit is low, and viscosity is high.

The shear history and peak shear terms show various degrees of influence on the models across formulations for both cone penetration and complex viscosity. The heat exchanger shear history (HXSH) is insignificant for the 50% formulation model of complex viscosity, while being relatively strong for the 80 and 40% case. In a similar manner, the secondary unit peak shear (SUPS) has no significance for complex viscosity at the 40%, while being exceptionally strong in the other oil levels.

CHAPTER V

CONCLUSIONS

There are shortcomings to this study of margarine and tablespread crystallization, however, the primary objectives for this study have been realized. The research conducted has resulted in an understanding of margarine and tablespread crystallization process operations which was unavailable previously. Utilization of results from this study will allow engineers and scientists working in the area of margarine manufacture to focus on key items, rather than factors of little importance.

The use of equipment settings and engineering parameters in the approach to the problem proved to be successful by closely correlating to texture products over a wide range of oil levels (40-80%). This shows potential for use with other complex processing operations. Another contribution of this research was the increased usefulness of engineering parameters for predicting effects of processing operations, as opposed to being restricted to use of unique equipment settings which are often studied. In this study the utilization of engineering parameters allowed for recognition of the role of the secondary unit, where equipment settings alone failed. Process design of crystallization steps in manufacture of margarine and tablespreads should be based on engineering parameters, instead of equipment settings, since they are key to scale-up and evaluation of alternate equipment options.

Engineering method for quantifing shear in batch mixer correlates well with flow-through margarine equipment. It is an important tool in process design and scale-up, and has the advantage of being simple and makes few assumptions. Use of the shear determination procedure allows for characterization of a particular piece of equipment, which becomes increasingly important as processes and equipment become more complex.

Results from this study have shown that different formulations have different processing requirements. As a result, processing of different formulations may require use of different equipment or at least control strategies. In the 40% oil formulation many factors are important, at the other extreme the 80% oil level has a few strong factors. In industry these products are normally produced on the same line, and approached with the same control strategies.

There are areas in which future research in the area of margarine and tablespreads manufacture would be beneficial. Testing and confirmation of the results which have been presented in this study should be conducted. Relating quantitative variables, such as complex viscosity or cone penetration depth, to consumer sensory information is an area of considerable potential. Further analysis of the interaction between specific formulation and processing would add insightful information that would complement this study. Probably the area most desperately in need of attention is the development of standardized methods for quantifying margarine and tablespread attributes. The lack of established criteria, as are found in other areas, is a serious shortcoming in the margarine and tablespread industry.

NOMENCLATURE

c	exponential constant in PO vs. RE, dimensionless
D	mixer characteristic diameter, m
DT	SSHE rate of cooling, °C/sec
dT	change in temperature, °C
dt	change in time, sec
E_V	viscous dissipation of energy, W
FLOW	process flowrate, kg/min
g	gap for shear, m
G'	loss modulus, 1000 dyn/cm^2
G''	storage modulus, 1000 dyn/cm^2
h	slit height, m
HXPS	SSHE peak shear, sec^{-1}
HXSH	SSHE shear history, dimensionless
K	consistency coefficient
K_p	constant in PO vs. RE , dimensionless
L	characteristic length, m
N	rotational speed, rev/sec
n	power-law index, dimensionless
PO	power number, dimensionless
P_w	total power input (shaft work), W
Q	flowrate through slit, m^3/s
Q_n	net flow rate, m^3/ s
r_a	average radius of SU agitator, m
RE	Reynolds number, dimensionless
r_o	outside radius of SU agitator, m
RPMS	rotational speed of heat exchanger, rad/sec
RPMW	rotational speed of secondary unit, rad/sec
SA	surface area of heat exchanger, m^2
SUPS	secondary unit peak shear, sec^{-1}
SUSH	secondary unit shear history, dimensionless
t_{sshe}	residence time in SSHE, sec
t_{su}	residence time in SU, sec

w	slit width, m
ΔP	pressure drop across equipment, Pa
ΔT	time change in cooling rate, sec
η^*	complex viscosity, 1000 Poise
η_a	apparent viscosity, Pa-s
γ	shear rate, sec^{-1}
γ_a	average shear rate, sec^{-1}
$\gamma_{a\text{-sshe}}$	average shear in SSHE, sec^{-1}
$\gamma_{a\text{-su}}$	average shear in SU, sec^{-1}
$\gamma_{p\text{-sshe}}$	peak shear in SSHE, sec^{-1}
$\gamma_{p\text{-su}}$	peak shear in SU, sec^{-1}
μ	Newtonian viscosity, pa-s
Φ_{SSHE}	shear history in SSHE, dimensionless
Φ_{SU}	shear history in secondary unit, dimensionless
ρ	fluid density, kg/m^3

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APPENDICES

APPENDIX A

EXPERIMENTAL RESULTS

Table A1.) Experimental treatments and results for 80% oil formulation trials.

Trt	SA	RPMS	FLOW	RPMW	CONE	G'	G"	η*
	ft^2	rpm	#/min	rpm	10^{-1} mm	10^2 dyn/cm^2	10^2 dyn/cm^2	10^2 Poise
5	2	400	8.75	275	164.7	5583	1725	5844
4	2	200	16.25	625	107.0	19060	5468	19830
8	2	400	16.25	625	105.7	18180	5586	19020
3	2	200	16.25	275	105.5	17660	4890	18330
7	2	400	16.25	275	105.7	16190	4468	16790
9	2	300	12.50	450	117.5	14930	5168	15500
1	2	200	8.75	275	129.0	8973	2670	9361
5	2	400	8.75	275	147.0	5118	1630	5372
2	2	200	8.75	625	125.5	11230	3291	11700
10	2	300	12.50	450	109.3	9360	3044	9842
13	4	300	5.00	450	213.5	4489	1430	4711
17	4	300	12.50	450	149.5	8470	2690	8887
16	4	300	12.50	800	146.0	8403	2698	8826
12	4	500	12.50	450	148.7	5366	1522	5578
18	4	300	12.50	450	140.0	9430	2824	9844
14	4	300	20.00	450	121.3	13660	3812	14180
15	4	300	12.50	100	134.3	11230	3328	11710
19	4	300	12.50	450	133.0	9940	2947	10370
20	4	300	12.50	450	131.5	6982	1784	7206
11	4	100	12.50	450	130.7	7241	2032	7521

Table A2.) Experimental treatments and results for 50% oil formulation trials.

Trt	SA	RPMS	FLOW	RPMW	CONE	G'	G''	η*
	ft^2	rpm	#/min	rpm	10^{-1} mm	10^2 dyn/cm^2	10^2 dyn/cm^2	10^2 Poise
16	4	300	12.50	800	208.0	3169	743	3255
17	4	300	12.50	450	199.3	4336	1065	4464
18	4	300	12.50	450	176.7	5010	1286	5172
12	4	500	12.50	450	194.0	3156	717	3237
14	4	300	20.00	450	147.0	10360	3055	11060
19	4	300	12.50	450	183.7	4801	1256	4963
11	4	100	12.50	450	167.7	5434	1602	5665
15	4	300	12.50	100	179.3	5249	1478	5453
20	4	300	12.50	450	184.0	4482	1273	4660
13	4	300	5.00	450	198.3	2821	761	2922
9	2	300	12.50	450	164.3	6615	2016	6915
3	2	200	16.25	275	135.0	7977	3416	8677
5	2	400	8.75	275	211.3	4360	1245	4534
2	2	200	8.75	625	170.7	5281	1755	5565
7	2	400	16.25	275	138.0	6863	2863	7436
8	2	400	16.25	625	142.0	8271	3076	8825
4	2	200	16.25	625	130.0	9196	4154	10090
1	2	200	8.75	275	179.7	4121	1492	4382
10	2	300	12.50	450	155.7	6868	2430	7286
6	2	400	8.75	625	201.2	2670	747	2773

Table A3.) Experimental treatments and results for 40% oil formulation trials.

Trt	SA	RPMS	FLOW	RPMW	CONE	G'	G''	η^*
	ft^2	rpm	#/min	rpm	10^{-1} mm	10^2 dyn/cm^2	10^2 dyn/cm^2	10^2 Poise
13	4	300	5.00	450	256.3	1430	334	1468
20	4	300	12.50	450	234.8	1763	324	1792
15	4	300	12.50	100	231.0	1696	327	1727
17	4	300	12.50	450	231.0	1568	304	1597
16	4	300	12.50	800	234.3	1599	291	1625
19	4	300	12.50	450	224.3	1585	286	1610
14	4	300	20.00	450	207.0	2183	445	2227
12	4	500	12.50	450	232.3	1487	269	1511
18	4	300	12.50	450	225.3	1621	319	1652
11	4	100	12.50	450	208.3	2366	526	2424
5	2	400	8.75	275	263.3	1575	308	1604
6	2	400	8.75	625	237.0	1572	332	1607
8	2	400	16.25	625	200.7	2299	439	2340
3	2	200	16.25	275	157.3	6228	1535	6414
9	2	300	12.5	450	193.7	2906	608	2969
1	2	200	8.75	275	210.0	2429	494	2478
10	2	300	12.5	450	189.0	2863	579	2921
4	2	200	16.25	625	151.0	6179	1360	6327
7	2	400	16.25	275	169.3	3575	735	3650
2	2	200	8.75	625	206.0	2164	400	2201

APPENDIX B

SAS ANALYSIS FOR EQUIPMENT SETTINGS

```
NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB SOFT HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1              OPTIONS LINESIZE=72,PAGESIZE=60;
2             DATA SOFT;
3             INPUT SA RPMS FLOW RPMW CONE GP GPP ETA ;
4             SARPMS = SA * RPMS;
5             SAFLOW = SA * FLOW;
6             SARPMW = SA * RPMW;
7             RPMSRPMW = RPMS * RPMW;
8             FLOWRPMW = FLOW * RPMW;
9             FLOWRPMS = FLOW * RPMS;
10            RPMS2 = RPMS * RPMS;
11            FLOW2 = FLOW * FLOW;
12            RPMW2 = RPMW * RPMW;
13            CARDS;

NOTE: DATA SET WORK.SOFT HAS 20 OBSERVATIONS AND 17 VARIABLES. 334 OBS/T
RK
NOTE: THE DATA STATEMENT USED 0.04 SECONDS AND 200K.

34            ;
35
35            PROC PRINT;
36
NOTE: THE PROCEDURE PRINT USED 0.06 SECONDS AND 212K
      AND PRINTED PAGE 1.

36            PROC REG DATA=SOFT;
37              MODEL CONE = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
38                           FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2
/ VIF R P;
39            OUTPUT OUT=GLMC  P=PRED R=RESID;
40
NOTE: THE DATA SET WORK.GLMC HAS 20 OBSERVATIONS AND 19 VARIABLES. 300
      OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 2 TO 3.

40            PROC PLOT DATA=GLMC;
41                PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
42                PLOT RESID * CONE / VREF=0;
43
NOTE: THE PROCEDURE PLOT USED 0.07 SECONDS AND 204K
      AND PRINTED PAGES 4 TO 5.

43            PROC REG DATA=SOFT;
44              MODEL ETA = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
45                          FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2/
 VIF R P;
```

Appendix B: SAS Analysis for Equipment Settings 80% Oil

```
46           OUTPUT OUT=GLMETA P=PRED R=RESID;
47
NOTE: THE DATA SET WORK.GLMETA HAS 20 OBSERVATIONS AND 19 VARIABLES.
      300 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 6 TO 7.

47           PROC PLOT DATA=GLMETA;
48               PLOT PRED*ETA='P' ETA*ETA='*' / OVERLAY;
49               PLOT RESID*ETA / VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.07 SECONDS AND 204K
      AND PRINTED PAGES 8 TO 9.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 1

21:25 TUESDAY, JANUARY 30, 1990

OBS	SA	RPMS	FLOW	RPMW	CONE	GP	GPP	ETA	SARPMS	SAFLOW	SARPMW	RPMSRPMW	FLOWRPMW	FLOWRPMS	RPMS2	FLOW2	RPMW2
1	-1	1	-1	-1	164.0	5583	1725	5844	-1	1	1	-1	1	-1	1	1	1
2	-1	-1	1	1	107.0	19060	5468	19830	1	-1	-1	-1	1	-1	1	1	1
3	-1	1	1	1	105.7	18180	5586	19020	-1	-1	-1	1	1	1	1	1	1
4	-1	-1	1	-1	105.5	17660	4890	18330	1	-1	1	1	-1	-1	1	1	1
5	-1	1	1	-1	105.7	16190	4468	16790	-1	-1	1	-1	-1	1	1	1	1
6	-1	0	0	0	117.5	14930	4168	15500	0	0	0	0	0	0	0	0	0
7	-1	-1	-1	-1	129.0	8973	2670	9361	1	1	1	1	1	1	1	1	1
8	-1	1	-1	-1	147.0	5118	1630	5372	-1	1	1	-1	1	-1	1	1	1
9	-1	-1	-1	1	125.5	11230	3291	11700	1	1	-1	-1	-1	1	1	1	1
10	-1	0	0	0	109.3	9360	3044	9842	0	0	0	0	0	0	0	0	0
11	1	0	-2	0	213.5	4489	1430	4711	0	-2	0	0	0	0	0	4	0
12	1	0	0	0	149.5	8470	2690	8887	0	0	0	0	0	0	0	0	0
13	1	0	0	2	146.0	8403	2698	8826	0	0	2	0	0	0	0	0	4
14	1	2	0	0	148.7	5366	1522	5578	2	0	0	0	0	0	4	0	0
15	1	0	0	0	140.0	9430	2824	9844	0	0	0	0	0	0	0	0	0
16	1	0	2	0	121.3	13660	3812	14180	0	2	0	0	0	0	0	4	0
17	1	0	0	-2	134.3	11230	3328	11710	0	0	-2	0	0	0	0	0	4
18	1	0	0	0	133.0	9940	2947	10370	0	0	0	0	0	0	0	0	0
19	1	0	0	0	131.5	6982	1784	7206	0	0	0	0	0	0	0	0	0
20	1	-2	0	0	130.7	7241	2032	7521	-2	0	0	0	0	0	4	0	0

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 2
21:25 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	11932.32861	917.87143	14.353	0.0018
ERROR	6	383.69689	63.94948087		
C TOTAL	19	12316.02550			

ROOT MSE	7.996842	R-SQUARE	0.9688
DEP MEAN	133.235	ADJ R-SQ	0.9013
C.V.	6.002058		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	126.23074	3.21752660	39.232	0.0001
SA	1	11.93237705	2.01553084	5.920	0.0010
RPMS	1	5.31577869	2.31262491	2.299	0.0612
FLOW	1	-19.97827869	2.31262491	-8.639	0.0001
RPMW	1	0.91270492	2.39440510	0.381	0.7162
SARPMS	1	-0.81577869	2.31262491	-0.353	0.7363
SAFLOW	1	-3.07172131	2.31262491	-1.328	0.2324
SARPMW	1	2.01229508	2.39440510	0.840	0.4329
FLOWRPMS	1	-6.40655738	3.66049872	-1.750	0.1307
FLOWRPMW	1	1.47459016	3.86510260	0.382	0.7160
RPMSRPMW	1	-0.59959016	3.86510260	-0.155	0.8818
RPMS2	1	0.44036885	1.60876330	0.274	0.7935
FLOW2	1	7.36536885	1.60876330	4.578	0.0038
RPMW2	1	0.55286885	1.60876330	0.344	0.7428

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.27049180
RPMS	1	1.33811475
FLOW	1	1.33811475
RPMW	1	1.41649590
SARPMS	1	1.33811475
SAFLOW	1	1.33811475
SARPMW	1	1.41649590
FLOWRPMS	1	1.67622951
FLOWRPMW	1	1.82213115
RPMSRPMW	1	1.82213115
RPMS2	1	1.10081967
FLOW2	1	1.10081967
RPMW2	1	1.10081967

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 3

21:25 TUESDAY, JANUARY 30, 1990

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	164.0	155.3	5.5611	8.7246	5.7466
2	107.0	107.0	7.9968	3.9E-14	5.1E-07
3	105.7	105.3	7.7302	0.4492	2.0478
4	105.5	105.1	7.7302	0.4492	2.0478
5	105.7	105.7	7.9968	1.4E-14	4.8E-07
6	117.5	114.3	3.8989	3.2016	6.9820
7	129.0	129.0	7.9968	5.0E-14	5.4E-07
8	147.0	155.3	5.5611	-8.2754	5.7466
9	125.5	125.1	7.7302	0.4492	2.0478
10	109.3	114.3	3.8989	-4.9984	6.9820
11	213.5	213.7	7.9310	-0.2246	1.0239
12	149.5	138.2	3.6917	11.3369	7.0937
13	146.0	146.2	7.9310	-0.2246	1.0239
14	148.7	148.9	7.9310	-0.2246	1.0239
15	140.0	138.2	3.6917	1.8369	7.0937
16	121.3	121.5	7.9310	-0.2246	1.0239
17	134.3	134.5	7.9310	-0.2246	1.0239
18	133.0	138.2	3.6917	-5.1631	7.0937
19	131.5	138.2	3.6917	-6.6631	7.0937
20	130.7	130.9	7.9310	-0.2246	1.0239

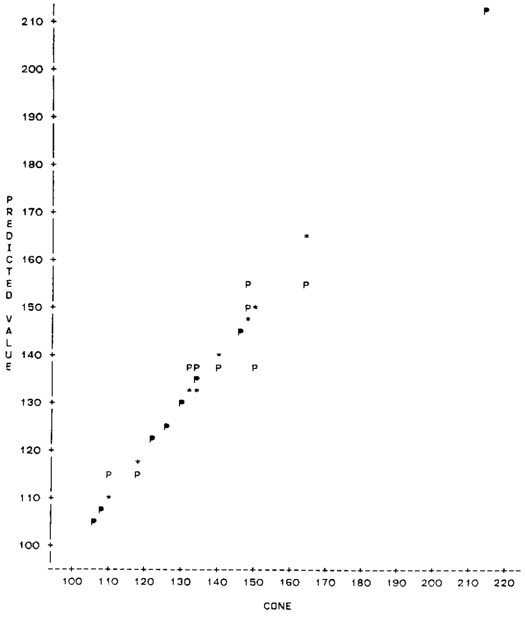
OBS	STUDENT RESIDUAL	-2 -1	0 1 2	COOK'S D
1	1.5182		***	0.154
2	7.7E-08			0.104
3	0.2193			0.049
4	0.2193			0.049
5	3.0E-08			0.017
6	0.4586			0.005
7	9.3E-08			0.137
8	-1.4401	**		0.139
9	0.2193			0.049
10	-0.7159	*		0.011
11	-0.2193			0.206
12	1.5982		***	0.049
13	-0.2193			0.206
14	-0.2193			0.206
15	0.2589			0.001
16	-0.2193			0.206
17	-0.2193			0.206
18	-0.7278	*		0.010
19	-0.9393	*		0.017
20	-0.2193			0.206

SUM OF RESIDUALS	8.27782E-13
SUM OF SQUARED RESIDUALS	383.6969
PREDICTED RESID SS (PRESS)	2428.455

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 4
21:25 TUESDAY, JANUARY 30, 1990

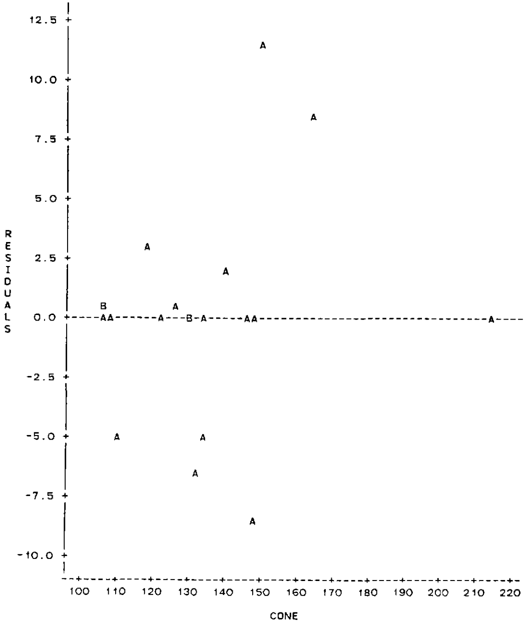
PLOT OF PRED*CONE SYMBOL USED IS P
PLOT OF CONE*CONE SYMBOL USED IS *



NOTE: 7 OBS HIDDEN

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 5
21:25 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*CONE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 6
21:25 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	406031865	31233220.39	7.969	0.0090
ERROR	6	23515798.75	3919299.79		
C TOTAL	19	429547664			

ROOT MSE	1979.722	R-SQUARE	0.9453
DEP MEAN	11021.1	ADJ R-SQ	0.8266
C.V.	17.96302		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	11076.38525	796.54053	13.906	0.0001
SA	1	-2242.64754	498.97085	-4.495	0.0041
RPMS	1	-874.00307	572.52035	-1.527	0.1777
FLOW	1	3658.37807	572.52035	6.390	0.0007
RPMW	1	129.62090	592.76610	0.219	0.8342
SARPMS	1	388.25307	572.52035	0.678	0.5230
SAFLOW	1	-1291.12807	572.52035	-2.255	0.0650
SARPMW	1	-850.62090	592.76610	-1.435	0.2013
FLOWRPMS	1	674.75615	906.20403	0.745	0.4846
FLOWRPMW	1	-47.74180328	956.85638	-0.050	0.9618
RPMSRPMW	1	20.49180328	956.85638	0.021	0.9836
RPMS2	1	-530.55738	398.27026	-1.332	0.2312
FLOW2	1	193.44262	398.27026	0.486	0.6444
RPMW2	1	399.06762	398.27026	1.002	0.3550

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.27049180
RPMS	1	1.33811475
FLOW	1	1.33811475
RPMW	1	1.41649590
SARPMS	1	1.33811475
SAFLOW	1	1.33811475
SARPMW	1	1.41649590
FLOWRPMS	1	1.67622951
FLOWRPMW	1	1.82213115
RPMSRPMW	1	1.82213115
RPMS2	1	1.10081967
FLOW2	1	1.10081967
RPMW2	1	1.10081967

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 7

21:25 TUESDAY, JANUARY 30, 1990

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	5844.0	5446.0	1376.7	398.0	1422.6
2	19830.0	19830.0	1979.7	1.3E-11	1.3E-04
3	19020.0	18696.0	1913.7	324.0	507.0
4	18330.0	18006.0	1913.7	324.0	507.0
5	16790.0	16790.0	1979.7	1.1E-11	1.2E-04
6	15500.0	13319.0	965.2	2181.0	1728.5
7	9361.0	9361.0	1979.7	1.1E-11	1.3E-04
8	5372.0	5446.0	1376.7	-73.9918	1422.6
9	11700.0	11376.0	1913.7	324.0	507.0
10	9842.0	13319.0	965.2	-3477.0	1728.5
11	4711.0	4873.0	1963.4	-162.0	253.5
12	8887.0	8833.7	913.9	53.2623	1756.1
13	8826.0	8988.0	1963.4	-162.0	253.5
14	5578.0	5740.0	1963.4	-162.0	253.5
15	9844.0	8833.7	913.9	1010.3	1756.1
16	14180.0	14342.0	1963.4	-162.0	253.5
17	11710.0	11872.0	1963.4	-162.0	253.5
18	10370.0	8833.7	913.9	1536.3	1756.1
19	7206.0	8833.7	913.9	-1627.7	1756.1
20	7521.0	7683.0	1963.4	-162.0	253.5

OBS	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	0.2798		0.005
2	1.0E-07		0.180
3	0.6391	*	0.416
4	0.6391	*	0.416
5	9.2E-08		0.167
6	1.2618	**	0.035
7	8.2E-08		0.107
8	-0.0520		0.000
9	0.6391	*	0.416
10	-2.0116	****	0.090
11	-0.6391	*	1.751
12	0.0303		0.000
13	-0.6391	*	1.751
14	-0.6391	*	1.751
15	0.5753	*	0.006
16	-0.6391	*	1.751
17	-0.6391	*	1.751
18	0.8748	*	0.015
19	-0.9269	*	0.017
20	-0.6391	*	1.751

```
SUM OF RESIDUALS                1.79170E-10
SUM OF SQUARED RESIDUALS          23515799
PREDICTED RESID SS (PRESS)       723493288
```

Appendix B: SAS Analysis for Equipment Settings 80% Oil

```
                          SAS                                         8
                                 21:25 TUESDAY, JANUARY 30, 1990
              PLOT OF PRED*ETA     SYMBOL USED IS P
              PLOT OF ETA*ETA      SYMBOL USED IS *
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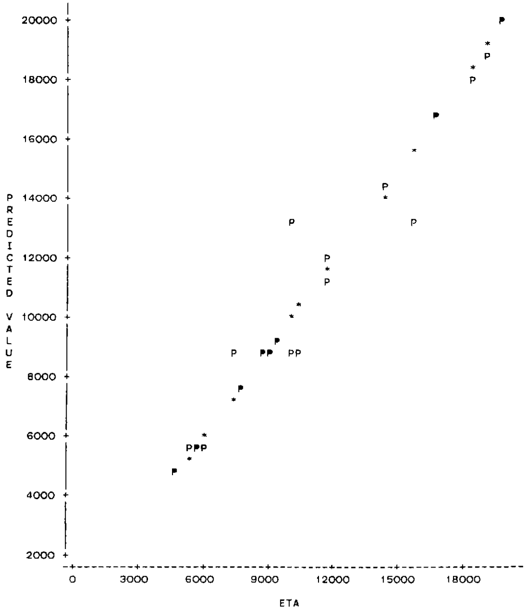
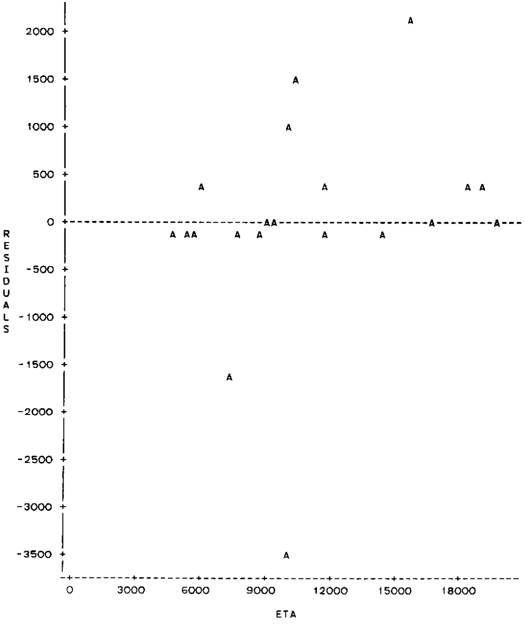


NOTE: 2 OBS HIDDEN

Appendix B: SAS Analysis for Equipment Settings 80% Oil

SAS 9
21:25 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*ETA LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix B: SAS Analysis for Equipment Settings 50% Oil

```
1          SAS(R) LOG   OS SAS 5.18          MVS/XA JOB SPREAD   STEP SAS
                                                                  21:45 T

NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB SPREAD HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1             OPTIONS LINESIZE=72,PAGESIZE=60;
2             DATA SPREAD;
3             INPUT SA RPMS FLOW RPMW CONE GP GPP ETA ;
4             SARPMS = SA * RPMS;
5             SAFLOW = SA * FLOW;
6             SARPMW = SA * RPMW;
7             RPMSRPMW = RPMS * RPMW;
8             FLOWRPMW = FLOW * RPMW;
9             FLOWRPMS = FLOW * RPMS;
10            RPMS2 = RPMS * RPMS;
11            FLOW2 = FLOW * FLOW;
12            RPMW2 = RPMW * RPMW;
13            CARDS;

NOTE: DATA SET WORK.SPREAD HAS 20 OBSERVATIONS AND 17 VARIABLES. 334 OBS
/TRK
NOTE: THE DATA STATEMENT USED 0.04 SECONDS AND 200K.

34            ;
35
35            PROC PRINT;
36
NOTE: THE PROCEDURE PRINT USED 0.06 SECONDS AND 212K
      AND PRINTED PAGE 1.

36            PROC REG DATA=SPREAD;
37              MODEL CONE = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
38                           FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2
/ VIF R P;
39            OUTPUT OUT=GLMC  P=PRED R=RESID;
40
NOTE: THE DATA SET WORK.GLMC HAS 20 OBSERVATIONS AND 19 VARIABLES. 300
      OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 2 TO 3.

40            PROC PLOT DATA=GLMC;
41                PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
42                PLOT RESID * CONE / VREF=0;
43
NOTE: THE PROCEDURE PLOT USED 0.07 SECONDS AND 204K
      AND PRINTED PAGES 4 TO 5.

43            PROC REG DATA=SPREAD;
44              MODEL ETA = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
45                          FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2/
 VIF R P;
```

Appendix B: SAS Analysis for Equipment Settings 50% Oil

```
2          SAS(R) LOG   OS SAS 5.18          MVS/XA JOB SPREAD
                                       21:45 TUESDAY, JANUARY 30, 1990

46            OUTPUT OUT=GLMETA P=PRED R=RESID;
47
NOTE: THE DATA SET WORK.GLMETA HAS 20 OBSERVATIONS AND 19 VARIABLES.
      300 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 6 TO 7.

47            PROC PLOT DATA=GLMETA;
48                PLOT PRED*ETA='P' ETA*ETA='*' / OVERLAY;
49                PLOT RESID*ETA / VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.07 SECONDS AND 204K
      AND PRINTED PAGES 8 TO 9.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 1

21:45 TUESDAY, JANUARY 30, 1990

OBS	SA	RPMS	FLOW	RPMW	CONE	GP	GPP	ETA	SARPMS	SAFLOW	SARPMW	RPMSRPMW	FLOWRPMW	FLOWRPMS	RPMS2	FLOW2	RPMW2
1	1	0	0	2	208.0	3169	743	3255	0	0	2	0	0	0	0	0	4
2	1	0	0	0	199.3	4336	1065	4464	0	0	0	0	0	0	0	0	0
3	1	0	0	0	176.7	5010	1286	5172	0	0	0	0	0	0	0	0	0
4	1	2	0	0	194.0	3156	717	3237	2	0	0	0	0	0	4	0	0
5	1	0	2	0	147.0	10360	3055	11060	0	2	0	0	0	0	0	4	0
6	1	0	0	0	183.7	4801	1256	4963	0	0	0	0	0	0	0	0	0
7	1	-2	0	0	167.7	5434	1602	5665	-2	0	0	0	0	0	4	0	0
8	1	0	0	-2	179.3	5249	1478	5453	0	0	-2	0	0	0	0	0	4
9	1	0	0	0	184.0	4482	1273	4660	0	0	0	0	0	0	0	0	0
10	1	0	-2	0	198.3	2821	761	2922	0	-2	0	0	0	0	0	4	0
11	-1	0	0	0	164.3	6615	2016	6915	0	0	0	0	0	0	0	0	0
12	-1	-1	1	-1	135.0	7977	3416	8677	1	-1	1	1	-1	-1	1	1	1
13	-1	1	-1	-1	211.3	4360	1245	4534	-1	1	1	-1	1	-1	1	1	1
14	-1	-1	-1	1	170.7	5281	1755	5565	1	1	-1	-1	-1	1	1	1	1
15	-1	1	1	-1	138.0	6863	2863	7436	-1	-1	1	-1	-1	1	1	1	1
16	-1	1	1	1	142.0	8271	3076	8825	-1	-1	-1	1	1	1	1	1	1
17	-1	-1	1	1	130.0	9196	4154	10090	1	-1	-1	-1	1	-1	1	1	1
18	-1	-1	-1	-1	179.7	4121	1492	4382	1	1	1	1	1	1	1	1	1
19	-1	0	0	0	155.7	6868	2430	7286	0	0	0	0	0	0	0	0	0
20	-1	1	-1	1	201.2	2670	747	2773	-1	1	-1	1	-1	-1	1	1	1

Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 2
21:45 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	11788.98852	906.84527	14.854	0.0017
ERROR	6	366.30098	61.05016288		
C TOTAL	19	12155.28950			

ROOT MSE	7.81346	R-SQUARE	0.9699
DEP MEAN	173.295	ADJ R-SQ	0.9046
C.V.	4.508763		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	174.07955	3.11649257	55.858	0.0001
SA	1	10.50500000	1.74714285	6.013	0.0010
RPMS	1	8.10625000	1.95336509	4.150	0.0060
FLOW	1	-20.03125000	1.95336509	-10.255	0.0001
RPMW	1	2.33125000	1.95336509	1.193	0.2777
SARPMS	1	-1.53125000	1.95336509	-0.784	0.4629
SAFLOW	1	7.20625000	1.95336509	3.689	0.0102
SARPMW	1	4.84375000	1.95336509	2.480	0.0478
FLOWRPMS	1	-5.88750000	2.76247540	-2.131	0.0771
FLOWRPMW	1	2.26250000	2.76247540	0.819	0.4441
RPMSRPMW	1	0.98750000	2.76247540	0.357	0.7330
RPMS2	1	-0.71022727	1.55824628	-0.456	0.6646
FLOW2	1	-2.76022727	1.55824628	-1.771	0.1269
RPMW2	1	2.48977273	1.55824628	1.598	0.1612

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.00000000
RPMS	1	1.00000000
FLOW	1	1.00000000
RPMW	1	1.00000000
SARPMS	1	1.00000000
SAFLOW	1	1.00000000
SARPMW	1	1.00000000
FLOWRPMS	1	1.00000000
FLOWRPMW	1	1.00000000
RPMSRPMW	1	1.00000000
RPMS2	1	1.08181818
FLOW2	1	1.08181818
RPMW2	1	1.08181818

Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 3
21:45 TUESDAY, JANUARY 30, 1990

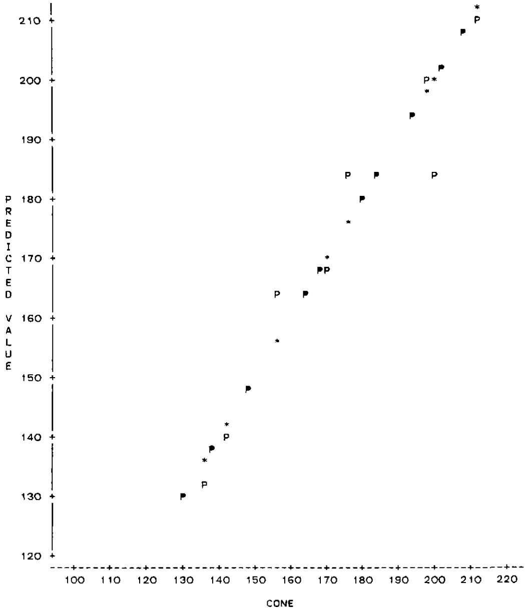
OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	208.0	208.9	7.7421	-0.8936	1.0536
2	199.3	184.6	3.5728	14.7155	6.9488
3	176.7	184.6	3.5728	-7.8845	6.9488
4	194.0	194.9	7.7421	-0.8936	1.0536
5	147.0	147.9	7.7421	-0.8936	1.0536
6	183.7	184.6	3.5728	-0.8845	6.9488
7	167.7	168.6	7.7421	-0.8936	1.0536
8	179.3	180.2	7.7421	-0.8936	1.0536
9	184.0	184.6	3.5728	-0.5845	6.9488
10	198.3	199.2	7.7421	-0.8936	1.0536
11	164.3	163.6	3.5728	0.7255	6.9488
12	135.0	132.8	7.2325	2.1561	2.9566
13	211.3	209.1	7.2325	2.1561	2.9566
14	170.7	168.5	7.2325	2.1561	2.9566
15	138.0	138.4	7.2325	-0.3689	2.9566
16	142.0	139.8	7.2325	2.1561	2.9566
17	130.0	130.4	7.2325	-0.3689	2.9566
18	179.7	180.1	7.2325	-0.3689	2.9566
19	155.7	163.6	3.5728	-7.8745	6.9488
20	201.2	201.6	7.2325	-0.3689	2.9566

OBS	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	-0.8482	*	2.775
2	2.1177	****	0.085
3	-1.1347	**	0.024
4	-0.8482	*	2.775
5	-0.8482	*	2.775
6	-0.1273		0.000
7	-0.8482	*	2.775
8	-0.8482	*	2.775
9	-0.0841		0.000
10	-0.8482	*	2.775
11	0.1044		0.000
12	0.7293	*	0.227
13	0.7293	*	0.227
14	0.7293	*	0.227
15	-0.1248		0.007
16	0.7293	*	0.227
17	-0.1248		0.007
18	-0.1248		0.007
19	-1.1332	**	0.024
20	-0.1248		0.007

SUM OF RESIDUALS 6.75016E-13
SUM OF SQUARED RESIDUALS 366.301
PREDICTED RESID SS (PRESS) 15975.26

Appendix B: SAS Analysis for Equipment Settings 50% Oil

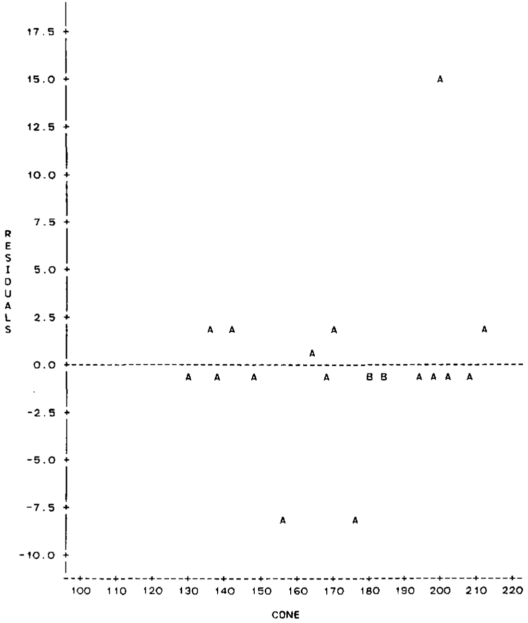
SAS 4
21:45 TUESDAY, JANUARY 30, 1990
PLOT OF PRED*CONE SYMBOL USED IS P
PLOT OF CONE*CONE SYMBOL USED IS *



NOTE: 4 OBS HIDDEN

Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 5
21:45 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*CONE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 6
21:45 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	105636355	8125873.49	20.482	0.0007
ERROR	6	2380432.89	396738.82		
C TOTAL	19	108016788			

ROOT MSE	629.8721	R-SQUARE	0.9780
DEP MEAN	5866.7	ADJ R-SQ	0.9302
C.V.	10.73639		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	5793.40909	251.23204	23.060	0.0001
SA	1	-781.60000	140.84367	-5.549	0.0014
RPMS	1	-625.12500	157.46802	-3.970	0.0074
FLOW	1	2128.12500	157.46802	13.515	0.0001
RPMW	1	-135.75000	157.46802	-0.862	0.4218
SARPMS	1	18.12500000	157.46802	0.115	0.9121
SAFLOW	1	-93.62500000	157.46802	-0.595	0.5739
SARPMW	1	-413.75000	157.46802	-2.628	0.0392
FLOWRPMS	1	16.75000000	222.69340	0.075	0.9425
FLOWRPMW	1	422.50000	222.69340	1.897	0.1066
RPMSRPMW	1	-371.00000	222.69340	-1.666	0.1468
RPMS2	1	-173.04545	125.61602	-1.378	0.2175
FLOW2	1	461.95455	125.61602	3.678	0.0104
RPMW2	1	-197.29545	125.61602	-1.571	0.1673

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.00000000
RPMS	1	1.00000000
FLOW	1	1.00000000
RPMW	1	1.00000000
SARPMS	1	1.00000000
SAFLOW	1	1.00000000
SARPMW	1	1.00000000
FLOWRPMS	1	1.00000000
FLOWRPMW	1	1.00000000
RPMSRPMW	1	1.00000000
RPMS2	1	1.08181818
FLOW2	1	1.08181818
RPMW2	1	1.08181818

Appendix B: SAS Analysis for Equipment Settings 50% Oil

```
SAS                                  7
21:45 TUESDAY, JANUARY 30, 1990
```

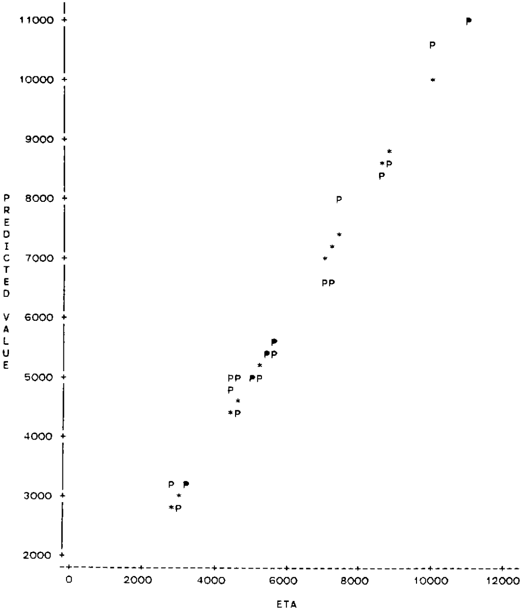
OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	3255.0	3123.6	624.1	131.4	84.9319
2	4464.0	5011.8	288.0	-547.8	560.2
3	5172.0	5011.8	288.0	160.2	560.2
4	3237.0	3105.6	624.1	131.4	84.9319
5	11060.0	10928.6	624.1	131.4	84.9319
6	4963.0	5011.8	288.0	-48.8091	560.2
7	5665.0	5533.6	624.1	131.4	84.9319
8	5453.0	5321.6	624.1	131.4	84.9319
9	4660.0	5011.8	288.0	-351.8	560.2
10	2922.0	2790.6	624.1	131.4	84.9319
11	6915.0	6575.0	288.0	340.0	560.2
12	8677.0	8443.4	583.0	233.6	238.3
13	4534.0	4300.4	583.0	233.6	238.3
14	5565.0	5331.4	583.0	233.6	238.3
15	7436.0	7932.4	583.0	-496.4	238.3
16	8825.0	8591.4	583.0	233.6	238.3
17	10090.0	10586.4	583.0	-496.4	238.3
18	4382.0	4878.4	583.0	-496.4	238.3
19	7286.0	6575.0	288.0	711.0	560.2
20	2773.0	3269.4	583.0	-496.4	238.3

OBS	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	1.5468	***	9.229
2	-0.9779	*	0.018
3	0.2860		0.002
4	1.5468	***	9.229
5	1.5468	***	9.229
6	-0.0871		0.000
7	1.5468	***	9.229
8	1.5468	***	9.229
9	-0.6280	*	0.007
10	1.5468	***	9.229
11	0.6069	*	0.007
12	0.9802	*	0.411
13	0.9802	*	0.411
14	0.9802	*	0.411
15	-2.0826	****	1.854
16	0.9802	*	0.411
17	-2.0826	****	1.854
18	-2.0826	****	1.854
19	1.2693	**	0.030
20	-2.0826	****	1.854

SUM OF RESIDUALS 6.73026E-11
SUM OF SQUARED RESIDUALS 2380433
PREDICTED RESID SS (PRESS) 373684866

Appendix B: SAS Analysis for Equipment Settings 50% Oil

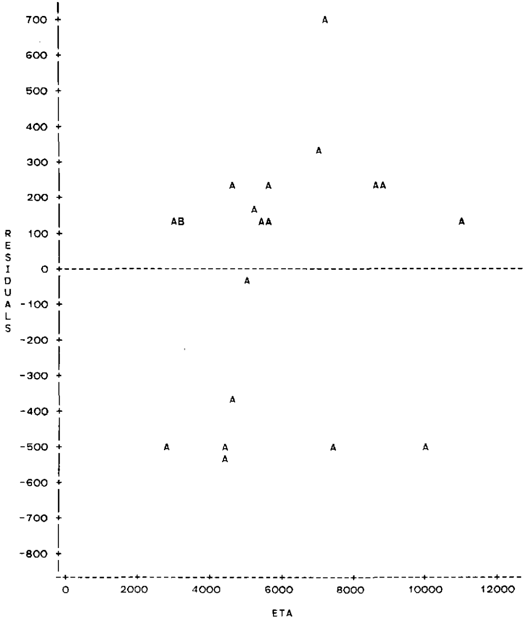
SAS 8
21:45 TUESDAY, JANUARY 30, 1990
PLOT OF PRED*ETA SYMBOL USED IS P
PLOT OF ETA*ETA SYMBOL USED IS *



NOTE: 5 OBS HIDDEN

Appendix B: SAS Analysis for Equipment Settings 50% Oil

SAS 9
21:45 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*ETA LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix B: SAS Analysis for Equipment Settings 40% Oil

```
1          SAS(R) LOG   OS SAS 5.18          MVS/XA JOB DIET     STEP SAS
                                                                  21:45 T

NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB DIET HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

1            OPTIONS LINESIZE=72,PAGESIZE=60;
2            DATA DIET;
3            INPUT SA RPMS FLOW RPMW CONE GP GPP ETA ;
4            SARPMS = SA * RPMS;
5            SAFLOW = SA * FLOW;
6            SARPMW = SA * RPMW;
7            RPMSRPMW = RPMS * RPMW;
8            FLOWRPMW = FLOW * RPMW;
9            FLOWRPMS = FLOW * RPMS;
10           RPMS2 = RPMS * RPMS;
11           FLOW2 = FLOW * FLOW;
12           RPMW2 = RPMW * RPMW;
13           CARDS;

NOTE: DATA SET WORK.DIET HAS 20 OBSERVATIONS AND 17 VARIABLES. 334 OBS/T
RK
NOTE: THE DATA STATEMENT USED 0.04 SECONDS AND 200K.

34           ;
35
35           PROC PRINT;
36
NOTE: THE PROCEDURE PRINT USED 0.06 SECONDS AND 212K
      AND PRINTED PAGE 1.

36           PROC REG DATA=DIET;
37             MODEL CONE = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
38                          FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2
/ VIF R P;
39           OUTPUT OUT=GLMC  P=PRED R=RESID;
40
NOTE: THE DATA SET WORK.GLMC HAS 20 OBSERVATIONS AND 19 VARIABLES. 300
      OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 2 TO 3.

40           PROC PLOT DATA=GLMC;
41               PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
42               PLOT RESID * CONE / VREF=0;
43
NOTE: THE PROCEDURE PLOT USED 0.07 SECONDS AND 204K
      AND PRINTED PAGES 4 TO 5.

43           PROC REG DATA=DIET;
44             MODEL ETA = SA RPMS FLOW RPMW SARPMS SAFLOW SARPMW
45                         FLOWRPMS FLOWRPMW RPMSRPMW RPMS2 FLOW2 RPMW2/
 VIF R P;
```

Appendix B: SAS Analysis for Equipment Settings 40% Oil

```
2          SAS(R) LOG   OS SAS 5.18           MVS/XA JOB DIET
                                          21:45 TUESDAY, JANUARY 30, 1990

46            OUTPUT OUT=GLMETA P=PRED R=RESID;
47
NOTE: THE DATA SET WORK.GLMETA HAS 20 OBSERVATIONS AND 19 VARIABLES.
      300 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.09 SECONDS AND 452K
      AND PRINTED PAGES 6 TO 7.

47            PROC PLOT DATA=GLMETA;
48                PLOT PRED*ETA='P' ETA*ETA='*' / OVERLAY;
49                PLOT RESID*ETA / VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.06 SECONDS AND 204K
      AND PRINTED PAGES 8 TO 9.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix B: SAS Analysis for Equipment Settings 40% Oil

SAS 1

21:45 TUESDAY, JANUARY 30, 1990

OBS	SA	RPMS	FLOW	RPMW	CONE	GP	GPP	ETA	SARPMS	SAFLOW	SARPMW	RPMSRPMW	FLOWRPMW	FLOWRPMS	RPMS2	FLOW2	RPMW2
1	1	0	-2	0	256.3	1430	334	1468	0	-2	0	0	0	0	0	4	0
2	1	0	0	0	234.8	1763	324	1792	0	0	0	0	0	0	0	0	0
3	1	0	0	-2	231.0	1696	327	1727	0	0	-2	0	0	0	0	0	4
4	1	0	0	0	231.0	1568	304	1597	0	0	0	0	0	0	0	0	0
5	1	0	0	2	234.3	1599	291	1625	0	0	2	0	0	0	0	0	4
6	1	0	0	0	224.3	1585	286	1610	0	0	0	0	0	0	0	0	0
7	1	0	2	0	207.0	2183	445	2227	0	2	0	0	0	0	0	4	0
8	1	2	0	0	232.3	1487	269	1511	2	0	0	0	0	0	4	0	0
9	1	0	0	0	225.3	1621	319	1652	0	0	0	0	0	0	0	0	0
10	1	-2	0	0	208.3	2366	526	2424	-2	0	0	0	0	0	4	0	0
11	-1	1	-1	-1	263.3	1575	308	1604	-1	1	1	-1	1	-1	1	1	1
12	-1	1	-1	1	237.0	1572	332	1607	-1	1	-1	1	-1	-1	1	1	1
13	-1	1	1	1	200.7	2299	439	2340	-1	-1	-1	1	1	1	1	1	1
14	-1	-1	1	-1	157.3	6228	1535	6414	1	-1	1	1	-1	-1	1	1	1
15	-1	0	0	0	193.7	2906	608	2969	0	0	0	0	0	0	0	0	0
16	-1	-1	-1	-1	210.0	2429	494	2478	1	1	1	1	1	1	1	1	1
17	-1	0	0	0	189.0	2863	579	2921	0	0	0	0	0	0	0	0	0
18	-1	-1	1	1	151.0	6179	1360	6327	1	-1	-1	-1	1	-1	1	1	1
19	-1	1	1	-1	169.3	3575	735	3650	-1	-1	1	-1	-1	1	1	1	1
20	-1	-1	-1	1	206.0	2164	400	2201	1	1	-1	-1	-1	1	1	1	1

Appendix B: SAS Analysis for Equipment Settings 40% Oil

SAS 2
21:45 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	16663.54195	1281.81092	12.451	0.0027
ERROR	6	617.70755	102.95126		
C TOTAL	19	17281.24950			

ROOT MSE	10.14649	R-SQUARE	0.9643
DEP MEAN	213.095	ADJ R-SQ	0.8868
C.V.	4.761487		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	211.63864	4.04704944	52.295	0.0001
SA	1	15.36500000	2.26882412	6.772	0.0005
RPMS	1	12.12500000	2.53662248	4.780	0.0031
FLOW	1	-21.03750000	2.53662248	-8.294	0.0002
RPMW	1	0.08750000	2.53662248	0.034	0.9736
SARPMS	1	-6.12500000	2.53662248	-2.415	0.0522
SAFLOW	1	8.71250000	2.53662248	3.435	0.0139
SARPMW	1	0.73750000	2.53662248	0.291	0.7810
FLOWRPMS	1	-2.82500000	3.58732591	-0.787	0.4610
FLOWRPMW	1	6.92500000	3.58732591	1.930	0.1018
RPMSRPMW	1	1.92500000	3.58732591	0.537	0.6108
RPMS2	1	-1.36818182	2.02352472	-0.676	0.5241
FLOW2	1	1.46931818	2.02352472	0.726	0.4951
RPMW2	1	1.71931818	2.02352472	0.850	0.4281

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.00000000
RPMS	1	1.00000000
FLOW	1	1.00000000
RPMW	1	1.00000000
SARPMS	1	1.00000000
SAFLOW	1	1.00000000
SARPMW	1	1.00000000
FLOWRPMS	1	1.00000000
FLOWRPMW	1	1.00000000
RPMSRPMW	1	1.00000000
RPMS2	1	1.08181818
FLOW2	1	1.08181818
RPMW2	1	1.08181818

Appendix B: SAS Analysis for Equipment Settings 40% Oil

SAS 3

21:45 TUESDAY, JANUARY 30, 1990

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	256.3	257.5	10.0538	-1.2309	1.3682
2	234.8	227.0	4.6396	7.7964	9.0236
3	231.0	232.2	10.0538	-1.2309	1.3682
4	231.0	227.0	4.6396	3.9964	9.0236
5	234.3	235.5	10.0538	-1.2309	1.3682
6	224.3	227.0	4.6396	-2.7036	9.0236
7	207.0	208.2	10.0538	-1.2309	1.3682
8	232.3	233.5	10.0538	-1.2309	1.3682
9	225.3	227.0	4.6396	-1.7036	9.0236
10	208.3	209.5	10.0538	-1.2309	1.3682
11	263.3	254.6	9.3920	8.7309	3.8394
12	237.0	243.3	9.3920	-6.2691	3.8394
13	200.7	192.0	9.3920	8.7309	3.8394
14	157.3	148.6	9.3920	8.7309	3.8394
15	193.7	196.3	4.6396	-2.5736	9.0236
16	210.0	216.3	9.3920	-6.2691	3.8394
17	189.0	196.3	4.6396	-7.2736	9.0236
18	151.0	157.3	9.3920	-6.2691	3.8394
19	169.3	175.6	9.3920	-6.2691	3.8394
20	206.0	197.3	9.3920	8.7309	3.8394

OBS	STUDENT RESIDUAL	-2 -1 0	1 2	COOK'S D
1	-0.8997	*		3.122
2	0.8640		*	0.014
3	-0.8997	*		3.122
4	0.4429			0.004
5	-0.8997	*		3.122
6	-0.2996			0.002
7	-0.8997	*		3.122
8	-0.8997	*		3.122
9	-0.1888			0.001
10	-0.8997	*		3.122
11	2.2740		****	2.210
12	-1.6328	***		1.140
13	2.2740		****	2.210
14	2.2740		****	2.210
15	-0.2852			0.002
16	-1.6328	***		1.140
17	-0.8061	*		0.012
18	-1.6328	***		1.140
19	-1.6328	***		1.140
20	2.2740		****	2.210

SUM OF RESIDUALS 1.53477E-12
SUM OF SQUARED RESIDUALS 617.7075
PREDICTED RESID SS (PRESS) 50275.29

Appendix B: SAS Analysis for Equipment Settings 40% Oil

```
                              SAS                                                  4
                                        21:45 TUESDAY, JANUARY 30, 1990
              PLOT OF PRED*CONE     SYMBOL USED IS P
              PLOT OF CONE*CONE     SYMBOL USED IS *
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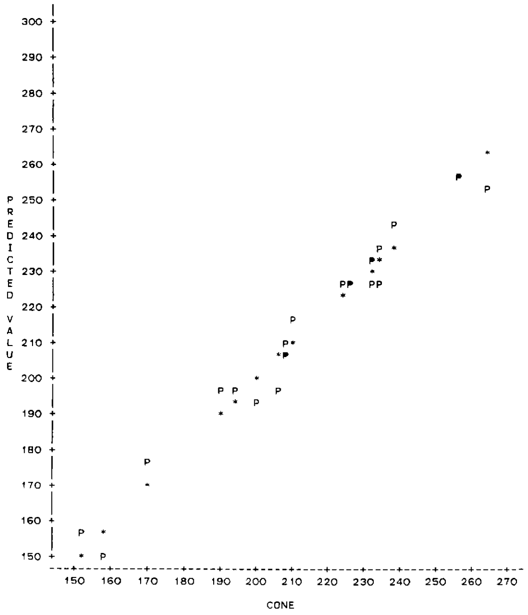
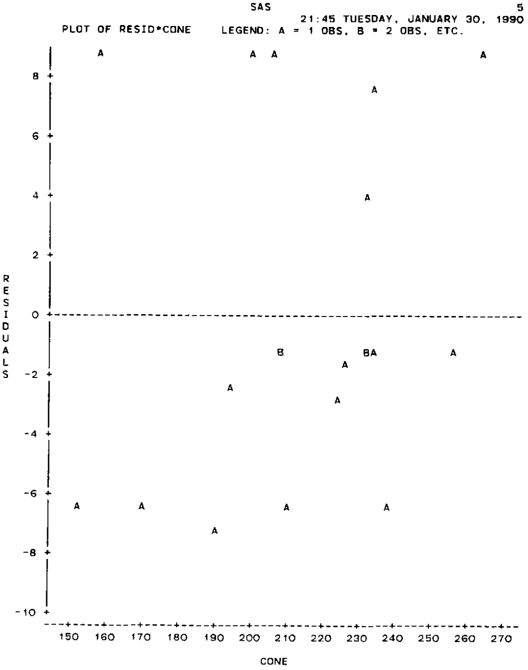


NOTE: 4 OBS HIDDEN

Appendix B: SAS Analysis for Equipment Settings 40% Oil



Appendix B: SAS Analysis for Equipment Settings 40% Oil

SAS 6
21:45 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	39329946.68	3025380.51	47.238	0.0001
ERROR	6	384274.52	64045.75265		
C TOTAL	19	39714221.20			

ROOT MSE	253.0726	R-SQUARE	0.9903
DEP MEAN	2507.2	ADJ R-SQ	0.9694
C.V.	10.09383		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	2350.59091	100.94106	23.287	0.0001
SA	1	-743.90000	56.58875889	-13.146	0.0001
RPMS	1	-627.81250	63.26815582	-9.923	0.0001
FLOW	1	772.43750	63.26815582	12.209	0.0001
RPMW	1	-117.18750	63.26815582	-1.852	0.1134
SARPMS	1	399.56250	63.26815582	6.315	0.0007
SAFLOW	1	-582.68750	63.26815582	-9.210	0.0001
SARPMW	1	91.68750000	63.26815582	1.449	0.1975
FLOWRPMS	1	-660.37500	89.47468403	-7.381	0.0003
FLOWRPMW	1	-140.37500	89.47468403	-1.569	0.1677
RPMSRPMW	1	-117.87500	89.47468403	-1.317	0.2358
RPMS2	1	99.54545455	50.47052856	1.972	0.0960
FLOW2	1	69.54545455	50.47052856	1.378	0.2174
RPMW2	1	26.67045455	50.47052856	0.528	0.6162

VARIABLE	DF	VARIANCE INFLATION
INTERCEP	1	0
SA	1	1.00000000
RPMS	1	1.00000000
FLOW	1	1.00000000
RPMW	1	1.00000000
SARPMS	1	1.00000000
SAFLOW	1	1.00000000
SARPMW	1	1.00000000
FLOWRPMS	1	1.00000000
FLOWRPMW	1	1.00000000
RPMSRPMW	1	1.00000000
RPMS2	1	1.08181818
FLOW2	1	1.08181818
RPMW2	1	1.08181818

Appendix B: SAS Analysis for Equipment Settings 40% Oil

SAS 7

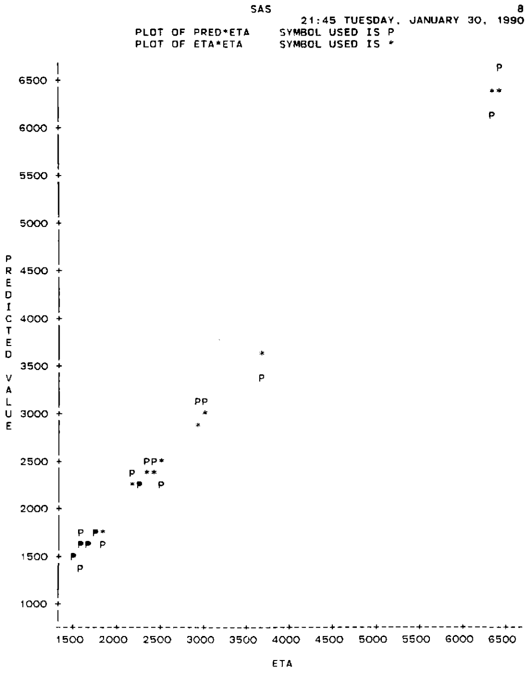
21:45 TUESDAY, JANUARY 30, 1990

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	1468.0	1505.4	250.8	-37.3727	34.1243
2	1792.0	1606.7	115.7	185.3	225.1
3	1727.0	1764.4	250.8	-37.3727	34.1243
4	1597.0	1606.7	115.7	-9.6909	225.1
5	1625.0	1662.4	250.8	-37.3727	34.1243
6	1610.0	1606.7	115.7	3.3091	225.1
7	2227.0	2264.4	250.8	-37.3727	34.1243
8	1511.0	1548.4	250.8	-37.3727	34.1243
9	1652.0	1606.7	115.7	45.3091	225.1
10	2424.0	2461.4	250.8	-37.3727	34.1243
11	1604.0	1754.5	234.3	-150.5	95.7611
12	1607.0	1381.8	234.3	225.2	95.7611
13	2340.0	2490.5	234.3	-150.5	95.7611
14	6414.0	6564.5	234.3	-150.5	95.7611
15	2969.0	3094.5	115.7	-125.5	225.1
16	2478.0	2252.8	234.3	225.2	95.7611
17	2921.0	3094.5	115.7	-173.5	225.1
18	6327.0	6101.8	234.3	225.2	95.7611
19	3650.0	3424.8	234.3	225.2	95.7611
20	2201.0	2351.5	234.3	-150.5	95.7611

OBS	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	-1.0952	**	4.626
2	0.8234	*	0.013
3	-1.0952	**	4.626
4	-0.0431		0.000
5	-1.0952	**	4.626
6	0.0147		0.000
7	-1.0952	**	4.626
8	-1.0952	**	4.626
9	0.2013		0.001
10	-1.0952	**	4.626
11	-1.5716	***	1.056
12	2.3522	****	2.365
13	-1.5716	***	1.056
14	-1.5716	***	1.056
15	-0.5576	*	0.006
16	2.3522	****	2.365
17	-0.7708	*	0.011
18	2.3522	****	2.365
19	2.3522	****	2.365
20	-1.5716	***	1.056

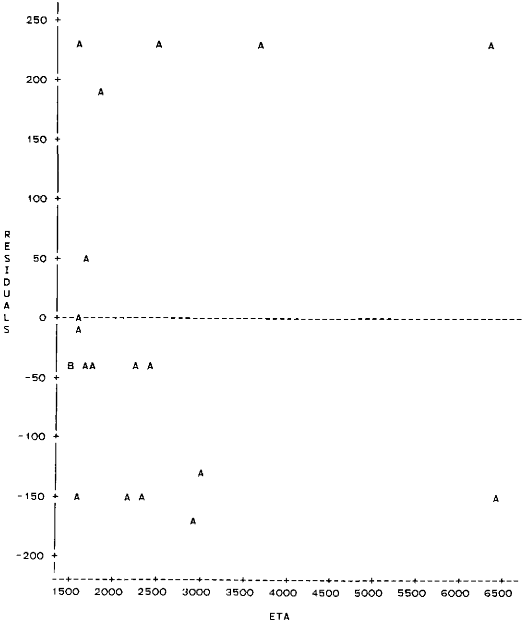
SUM OF RESIDUALS	6.70752E-12
SUM OF SQUARED RESIDUALS	384274.5
PREDICTED RESID SS (PRESS)	39800905

Appendix B: SAS Analysis for Equipment Settings 40% Oil



NOTE: 8 OBS HIDDEN

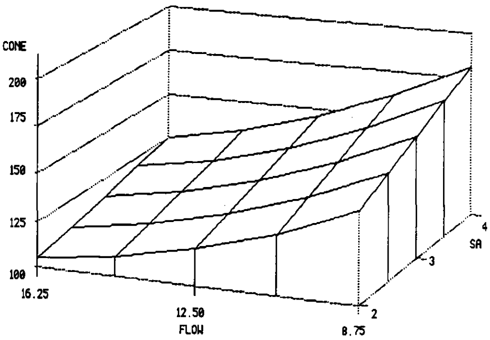
PLOT OF RESID*ETA LEGEND: A = 1 OBS, B = 2 OBS, ETC.

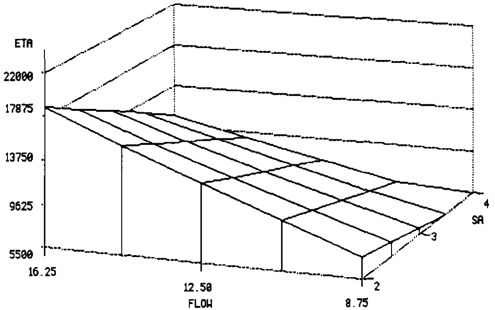


APPENDIX C

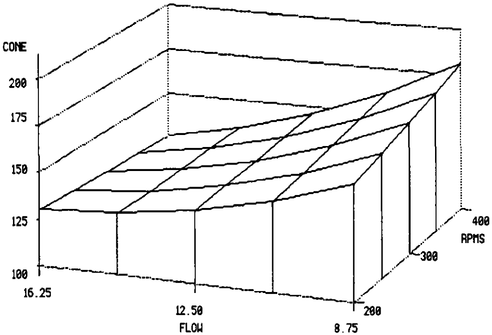
3-D GRAPHS OF EQUIPMENT SETTINGS VS. DEPENDENT VARIABLES

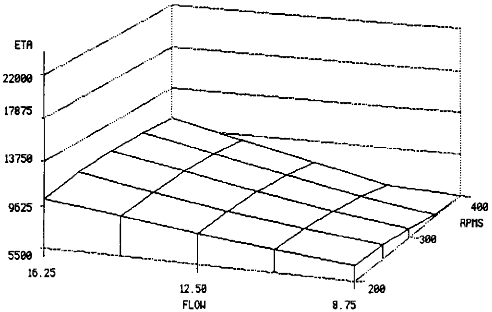
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



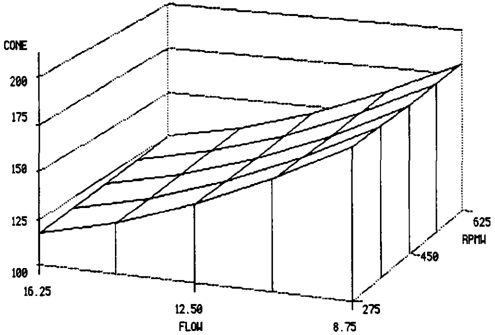


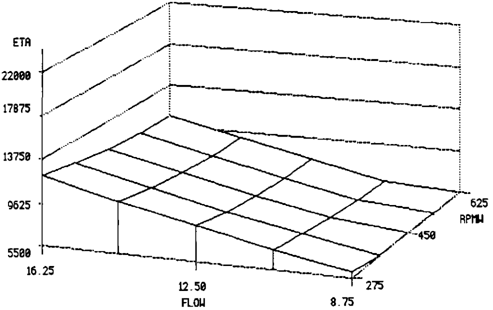
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



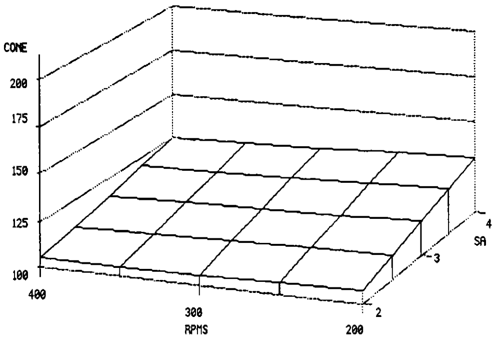


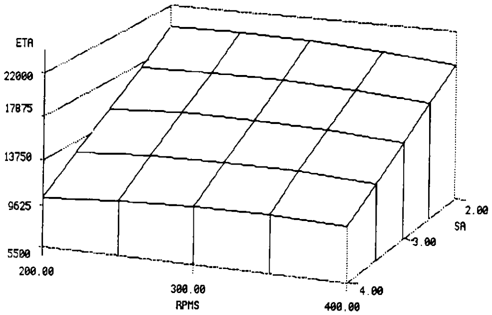
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



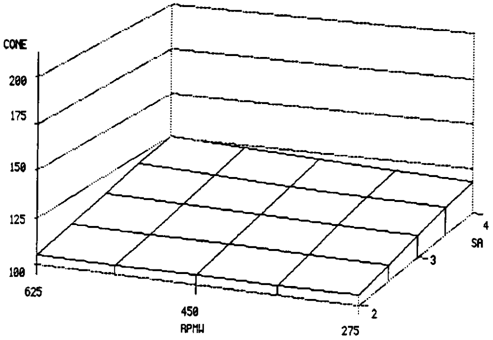


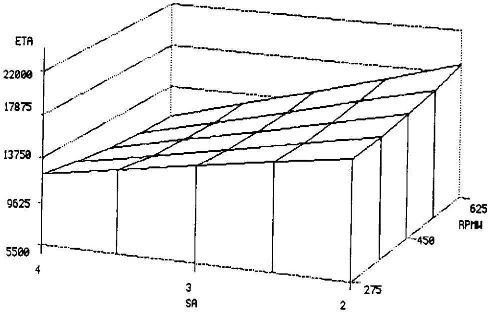
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



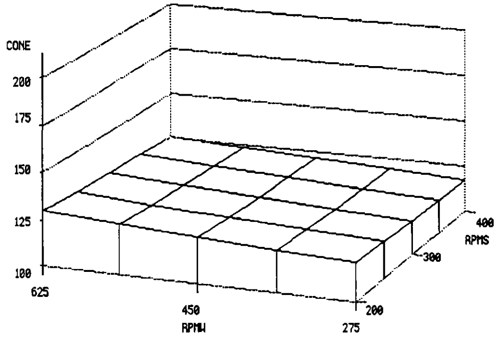


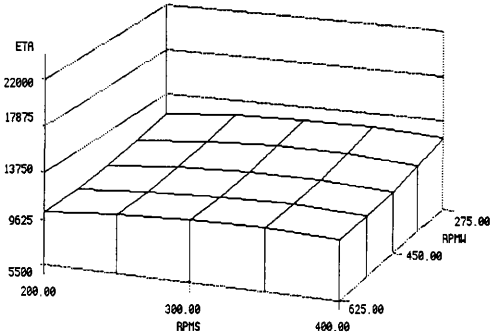
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



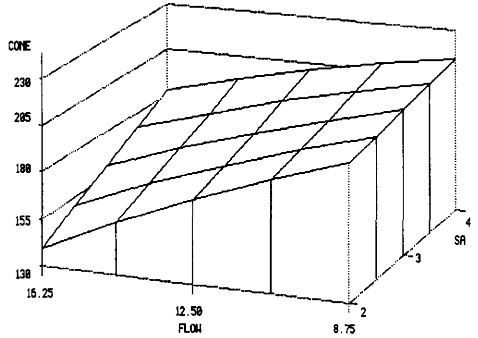


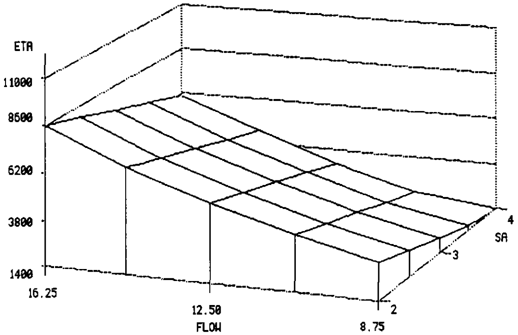
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 80% Oil



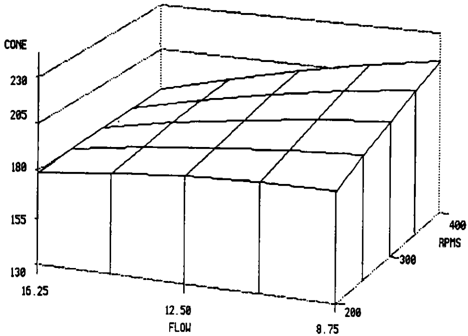


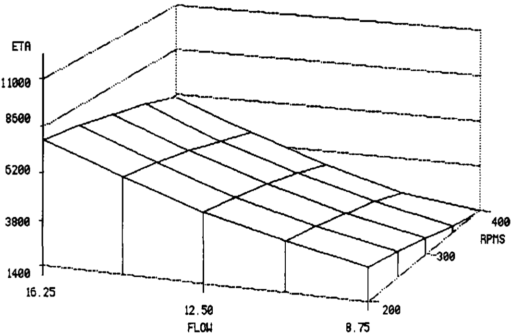
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



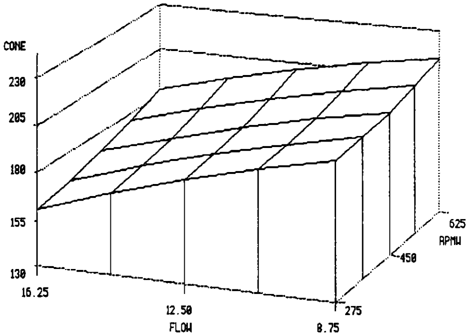


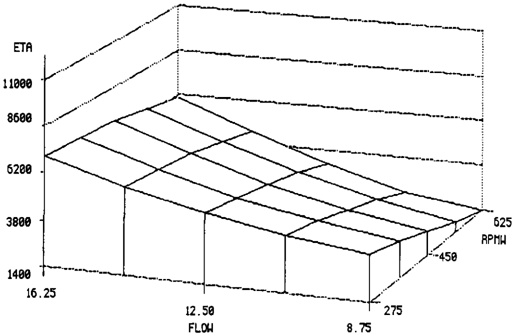
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



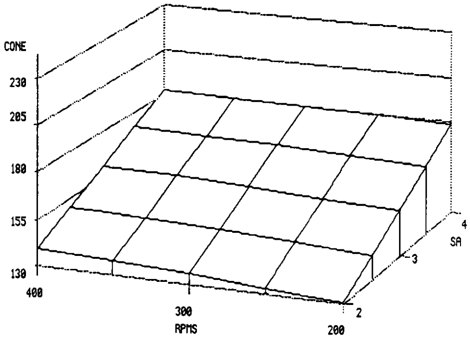


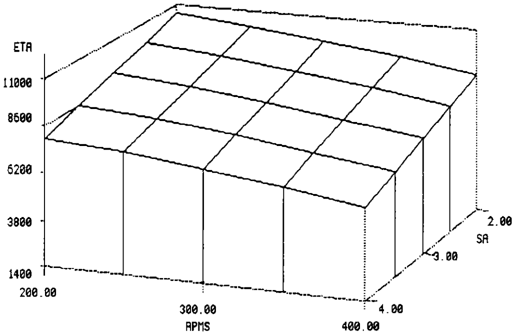
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



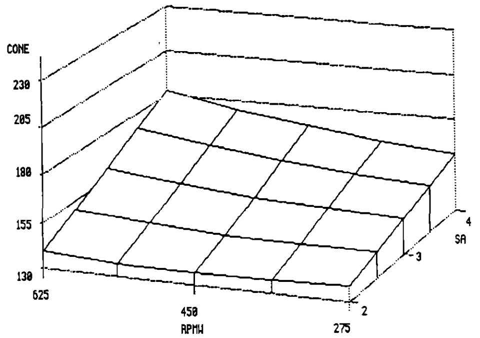


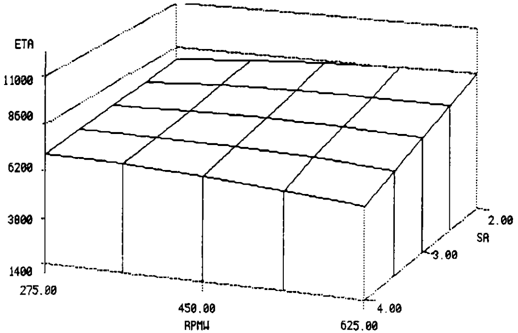
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



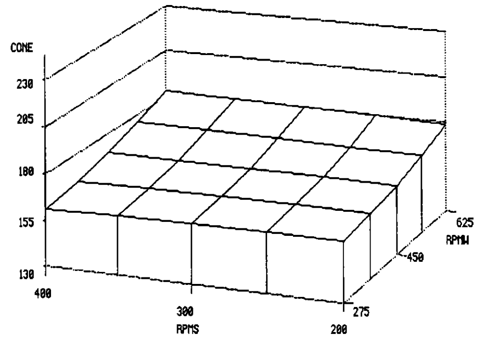


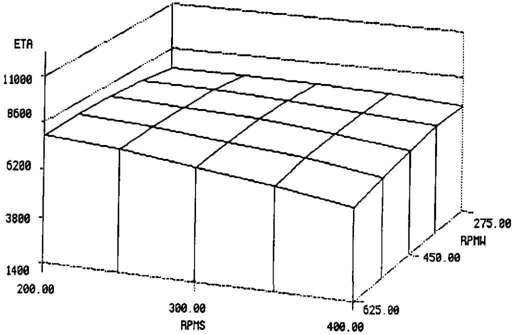
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



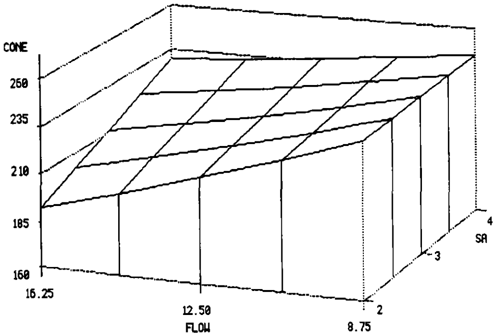


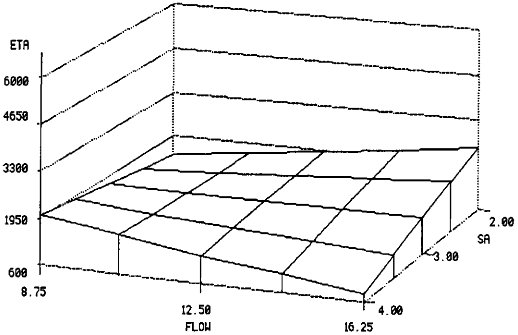
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 50% Oil



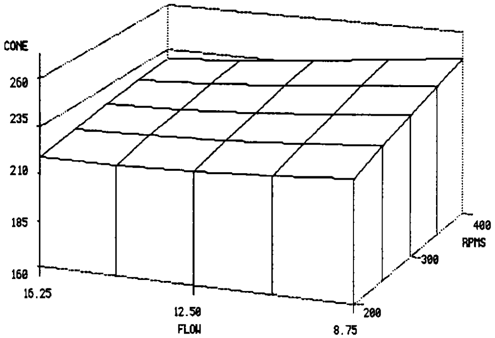


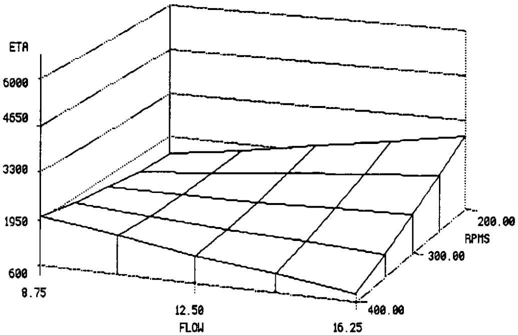
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil



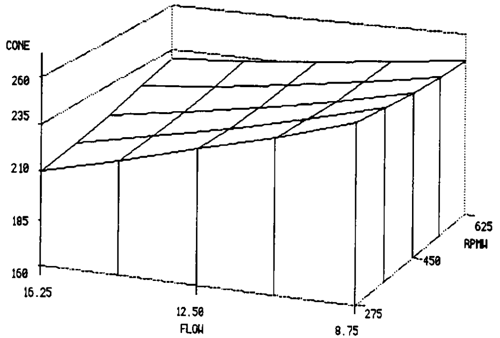


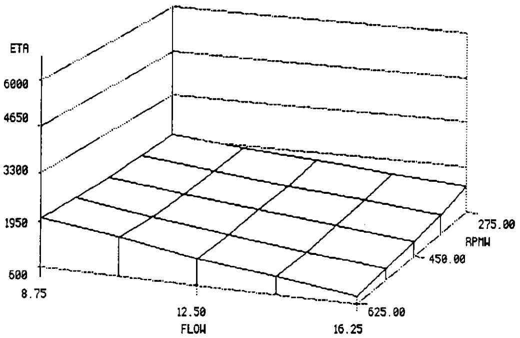
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil



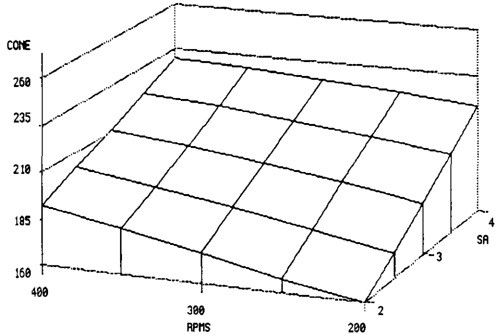


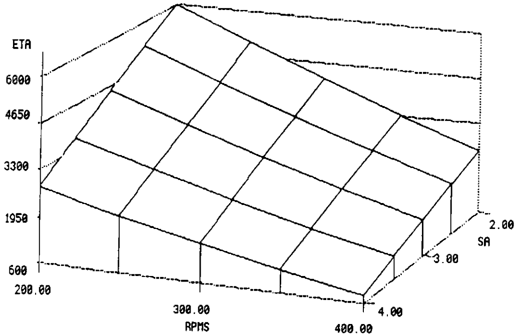
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil



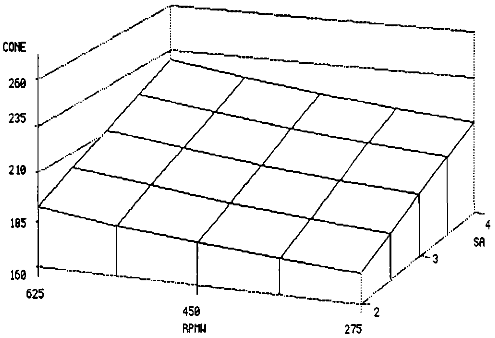


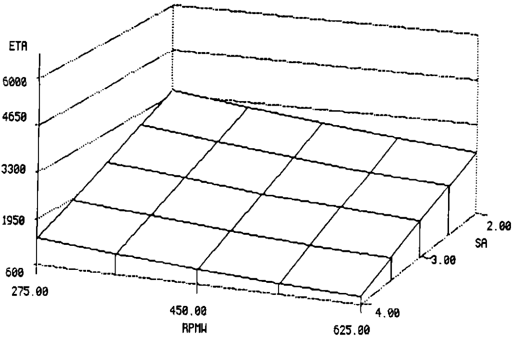
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil



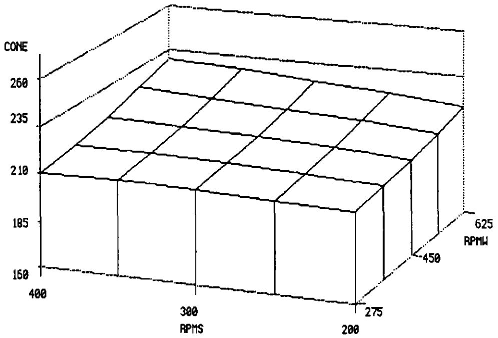


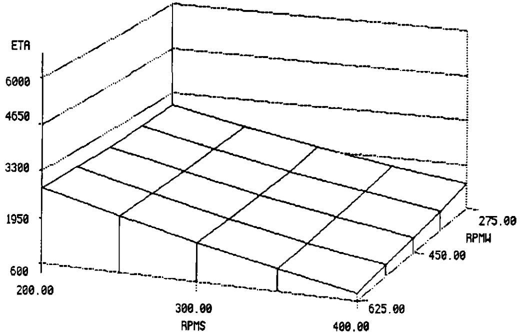
Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil





Appendix C:
3-D Graphs of Equipment Settings vs. Dependant Variables 40% Oil





APPENDIX D

SAS ANALYSIS FOR ENGINEERING PARAMETERS

```
NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB SOFT HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

          OPTIONS LINESIZE=72,PAGESIZE=60;
          DATA SOFT;
           DO SA=2 TO 4 BY .50;
              DO RPMS=200 TO 400 BY 50;
                 DO FLOW=8.75 TO 16.25 BY 1.875;
                    DO RPMW=275 TO 625 BY 87.5;
          CONE =  126.23
                  +(SA-3) * 11.932
                  +(RPMS-300)/100 * 5.316
                  -(FLOW-12.5)/3.75 * 19.978
                  +(RPMW-450)/175 * 0.9127
                  -(SA*RPMS-3*RPMS-300*SA+900)/100   *0.81577
                  -(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*3.0717
                  +(SA*RPMW-3*RPMW-450*SA+1350)/175  *2.012
                  -(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 0.600
                  +(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 1.475
                  -(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375 * 6.407
                  +(RPMS**2-600*RPMS+90000)/100**2 * 0.440
                  +(RPMW**2-900*RPMW+202500)/175**2 * 0.553
                  +(FLOW**2-25*FLOW+156.25)/3.75**2 * 7.365   ;
          ETA  =  11067.38
                  -(SA-3) * 2242.65
                  -(RPMS-300)/100 * 874.0
                  +(FLOW-12.5)/3.75 * 3658.38
                  +(RPMW-450)/175 * 129.62
                  +(SA*RPMS-3*RPMS-300*SA+900)/100   *388.25
                  -(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*1291.13
                  -(SA*RPMW-3*RPMW-450*SA+1350)/175  *850.62
                  +(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 20.49
                  -(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 47.74
                  +(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375     * 674.76
                  -(RPMS**2-600*RPMS+90000)/100**2 * 530.56
                  +(RPMW**2-900*RPMW+202500)/175**2 * 399.07
                  +(FLOW**2-25*FLOW+156.25)/3.75**2 * 193.44 ;
           DT = 27.778/ (SA * 0.0525 * 58.38/(FLOW/60))       ;
           HXSH = (56.541+23.16*RPMS/60-2.001*(RPMS/60)**2)
                  *(SA*0.0525*58.38/FLOW*60)                  ;
           HXPS =  6*(181.44*RPMS/60)/(0.25**2*20.875)        ;
           SUSH = ((2*3.14159*1.1875*RPMW/60)/0.28125)
                  *(58.38*0.5828/FLOW*60)                     ;
           SUPS =  (2*3.14159*1.875*RPMW/60)/0.28125          ;
                  OUTPUT;
               END;
             END;
           END;
         END;
```

Appendix D: SAS Analysis for Engineering Parameters 80% Oil

```
NOTE: DATA SET WORK.SOFT HAS 625 OBSERVATIONS AND 11 VARIABLES. 510 OBS/
TRK
NOTE: THE DATA STATEMENT USED 0.17 SECONDS AND 200K.

47          PROC REG DATA=SOFT;
48             MODEL CONE = DT HXSH HXPS SUSH SUPS
49                       / VIF SS2;
50             OUTPUT OUT=PCONE P=PRED R=RESID;
51
NOTE: THE DATA SET WORK.PCONE HAS 625 OBSERVATIONS AND 13 VARIABLES.
      434 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.15 SECONDS AND 452K
      AND PRINTED PAGE 1.

51            PROC PLOT DATA=PCONE;
52               PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
53               PLOT RESID*CONE /VREF=0;
54
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 2 TO 3.

54          PROC REG DATA=SOFT;
55             MODEL ETA  = DT HXSH HXPS SUSH SUPS
56                       / VIF SS2;
57             OUTPUT OUT=PCONE P=PRED R=RESID;
58
NOTE: THE DATA SET WORK.PCONE HAS 625 OBSERVATIONS AND 13 VARIABLES.
      434 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.14 SECONDS AND 452K
      AND PRINTED PAGE 4.

58            PROC PLOT DATA=PCONE;
59               PLOT PRED*ETA ='P' ETA*ETA='*' / OVERLAY;
60               PLOT RESID*ETA /VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 5 TO 6.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix D: SAS Analysis for Engineering Parameters 80% Oil

SAS 1
21:18 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	182432.84	36486.56897	2075.134	0.0001
ERROR	619	10883.72610	17.58275622		
C TOTAL	624	193316.57			

ROOT MSE	4.19318	R-SQUARE	0.9437
DEP MEAN	130.409	ADJ R-SQ	0.9432
C.V.	3.215407		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	81.81149886	2.69454616	30.362	0.0001
DT	1	-2.01705225	2.02340420	-0.997	0.3192
HXSH	1	0.006588201	0.000259280	25.410	0.0001
HXPS	1	0.002671359	0.000176481	15.137	0.0001
SUSH	1	0.000714710	0.000028094	25.440	0.0001
SUPS	1	-0.07005886	0.003613439	-19.388	0.0001

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	16208.55866	0
DT	1	17.47253656	7.18836775
HXSH	1	11352.23111	8.00929205
HXPS	1	4028.62770	1.07055884
SUSH	1	11379.54967	4.20475432
SUPS	1	6609.54520	3.46381501

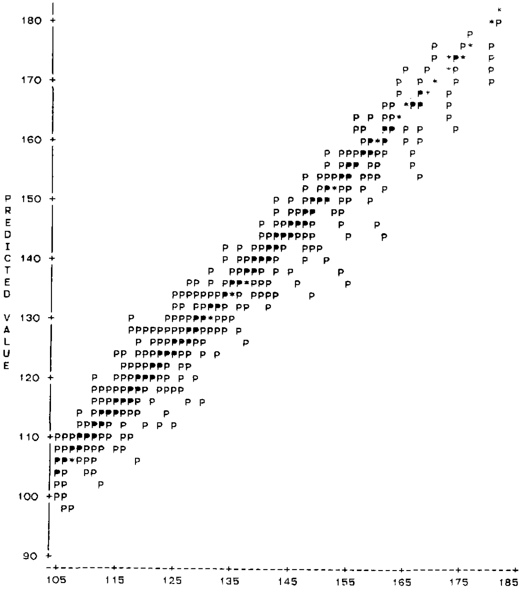
Appendix D: SAS Analysis for Engineering Parameters 80% Oil

SAS 2

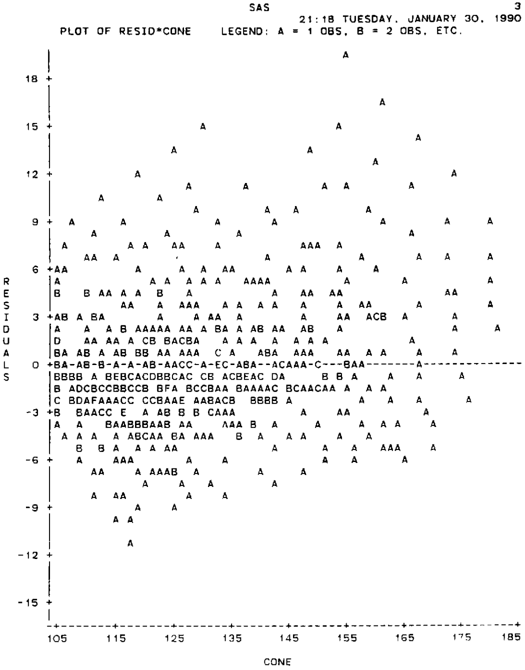
21:18 TUESDAY, JANUARY 30, 1990

PLOT OF PRED*CONE SYMBOL USED IS P

PLOT OF CONE*CONE SYMBOL USED IS *



NOTE: 848 OBS HIDDEN


SAS
3
21:18 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*CONE LEGEND: A = 1 OBS, B = 2 OBS, ETC.
RESIDUALS
18
15
12
9
6
3
0
-3
-6
-9
-12
-15
105
115
125
135
145
155
165
175
185
CONE

Appendix D: SAS Analysis for Engineering Parameters 80% Oil

SAS 4
21:18 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	6039864099	1207972820	1560.474	0.0001
ERROR	619	479171711	774106.16		
C TOTAL	624	6519035809			

ROOT MSE	879.833	R-SQUARE	0.9265
DEP MEAN	11098.35	ADJ R-SQ	0.9259
C.V.	7.927599		

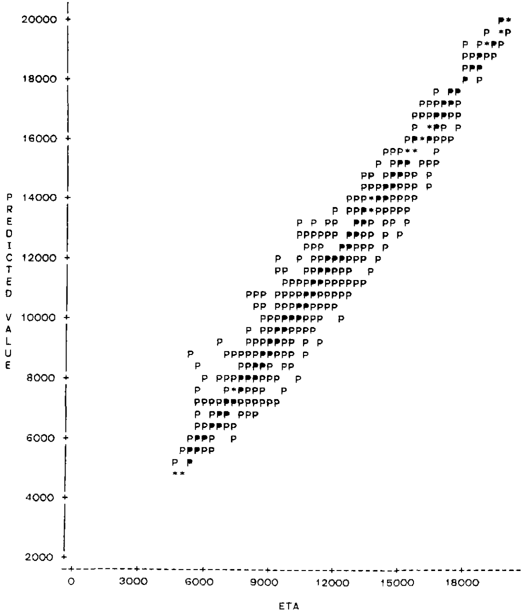
PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	3582.17205	565.38256	6.336	0.0001
DT	1	12433.99450	424.56035	29.287	0.0001
HXSH	1	0.31190436	0.05440346	5.733	0.0001
HXPS	1	-0.68297337	0.03703002	-18.444	0.0001
SUSH	1	-0.14381132	0.005894782	-24.396	0.0001
SUPS	1	16.66113305	0.75818913	21.975	0.0001

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	31074817.11	0
DT	1	663961659	7.18836775
HXSH	1	25444293.98	8.00929205
HXPS	1	263329850	1.07055884
SUSH	1	460734904	4.20475432
SUPS	1	373813067	3.46381501

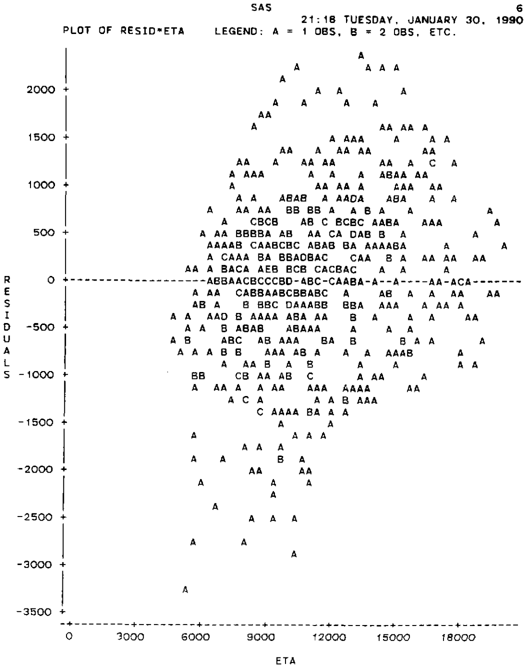
Appendix D: SAS Analysis for Engineering Parameters 80% Oil

```
                         SAS                                    5
                              21:18 TUESDAY, JANUARY 30, 1990
            PLOT OF PRED*ETA     SYMBOL USED IS P
            PLOT OF ETA*ETA      SYMBOL USED IS *
```



NOTE: 889 OBS HIDDEN

Appendix D: SAS Analysis for Engineering Parameters 80% Oil



Appendix D: SAS Analysis for Engineering Parameters 50% Oil

```
1          SAS(R) LOG   OS SAS 5.18            MVS/XA JOB SPREAD    STEP SAS
                                                                     21:19 1

NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB SPREAD HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

          OPTIONS LINESIZE=72,PAGESIZE=60;
          DATA SPREAD;
           DO SA=2 TO 4 BY .50;
              DO RPMS=200 TO 400 BY 50;
                 DO FLOW=8.75 TO 16.25 BY 1.875;
                    DO RPMW=275 TO 625 BY 87.5;
          CONE =  174.08
                  +(SA-3) * 10.505
                  +(RPMS-300)/100 * 8.106
                  -(FLOW-12.5)/3.75 * 20.031
                  +(RPMW-450)/175 * 2.331
                  -(SA*RPMS-3*RPMS-300*SA+900)/100   *1.5313
                  +(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*7.206
                  +(SA*RPMW-3*RPMW-450*SA+1350)/175  *4.844
                  +(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 0.9875
                  +(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 2.2625
                  -(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375 * 5.8875
                  -(RPMS**2-600*RPMS+90000)/100**2 * 0.710
                  +(RPMW**2-900*RPMW+202500)/175**2 * 2.490
                  -(FLOW**2-25*FLOW+156.25)/3.75**2 * 2.760     ;
         ETA   =  5793.41
                  -(SA-3) * 781.6
                  -(RPMS-300)/100 * 625.125
                  +(FLOW-12.5)/3.75 * 2128.125
                  -(RPMW-450)/175 * 135.75
                  +(SA*RPMS-3*RPMS-300*SA+900)/100   *18.125
                  -(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*93.625
                  -(SA*RPMW-3*RPMW-450*SA+1350)/175  *413.75
                  -(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 371.0
                  +(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 422.5
                  +(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375    * 16.75
                  -(RPMS**2-600*RPMS+90000)/100**2 * 173.05
                  -(RPMW**2-900*RPMW+202500)/175**2 * 197.29
                  +(FLOW**2-25*FLOW+156.25)/3.75**2 * 461.95 ;
           DT = 27.778/ (SA * 0.0525 * 58.38/(FLOW/60))       ;
           HXSH = (56.541+23.16*RPMS/60-2.001*(RPMS/60)**2)
                  *(SA*0.0525*58.38/FLOW*60)                   ;
           HXPS =  6*(181.44*RPMS/60)/(0.25**2*20.875) ;
           SUSH = ((2*3.14159*1.1875*RPMW/60)/0.28125)
                  *(58.38*0.5828/FLOW*60)                      ;
           SUPS =  (2*3.14159*1.875*RPMW/60)/0.28125           ;
                 OUTPUT;
              END;
           END;
        END;
     END;
```

Appendix D: SAS Analysis for Engineering Parameters 50% Oil

```
2          SAS(R) LOG   OS SAS 5.18            MVS/XA JOB SPREAD
                                            21:19 TUESDAY, JANUARY 30, 1990

NOTE: DATA SET WORK.SPREAD HAS 625 OBSERVATIONS AND 11 VARIABLES. 510 OB
S/TRK
NOTE: THE DATA STATEMENT USED 0.17 SECONDS AND 200K.

47           PROC REG DATA=SPREAD;
48              MODEL CONE = DT HXSH HXPS SUSH SUPS
49                         / VIF SS2;
50              OUTPUT OUT=PCONE P=PRED R=RESID;
51
NOTE: THE DATA SET WORK.PCONE HAS 625 OBSERVATIONS AND 13 VARIABLES.
      434 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.15 SECONDS AND 452K
      AND PRINTED PAGE 1.

51             PROC PLOT DATA=PCONE;
52                PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
53                PLOT RESID*CONE /VREF=0;
54
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 2 TO 3.

54           PROC REG DATA=SPREAD;
55              MODEL ETA  = DT HXSH HXPS SUSH SUPS
56                         / VIF SS2;
57              OUTPUT OUT=PETA  P=PRED R=RESID;
58
NOTE: THE DATA SET WORK.PETA HAS 625 OBSERVATIONS AND 13 VARIABLES. 434
      OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.15 SECONDS AND 452K
      AND PRINTED PAGE 4.

58             PROC PLOT DATA=PETA ;
59                PLOT PRED*ETA ='P' ETA*ETA='*' / OVERLAY:
60                PLOT RESID*ETA /VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 5 TO 6.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix D: SAS Analysis for Engineering Parameters 50% Oil

SAS 1
21:19 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	179678.87	35935.77426	988.314	0.0001
ERROR	619	22507.25312	36.36066740		
C TOTAL	624	202186.12			

ROOT MSE	6.029981	R-SQUARE	0.8887
DEP MEAN	173.59	ADJ R-SQ	0.8878
C.V.	3.473691		

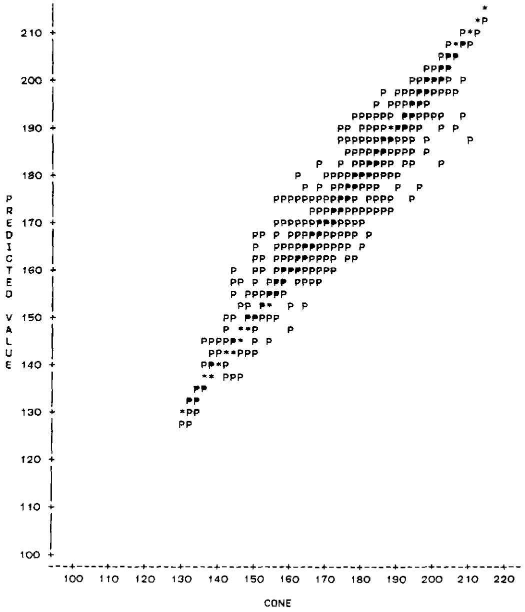
PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	195.82103	3.87487836	50.536	0.0001
DT	1	-64.76925011	2.90974609	-22.259	0.0001
HXSH	1	-0.001930505	0.000372857	-5.178	0.0001
HXPS	1	0.006166153	0.000253787	24.297	0.0001
SUSH	1	0.000828844	0.000040400	20.516	0.0001
SUPS	1	-0.07083072	0.005196288	-13.631	0.0001

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	92861.21135	0
DT	1	18016.04247	7.18836775
HXSH	1	974.74098	8.00929205
HXPS	1	21464.51779	1.07055884
SUSH	1	15304.18607	4.20475432
SUPS	1	6755.98591	3.46381501

Appendix D: SAS Analysis for Engineering Parameters 50% Oil

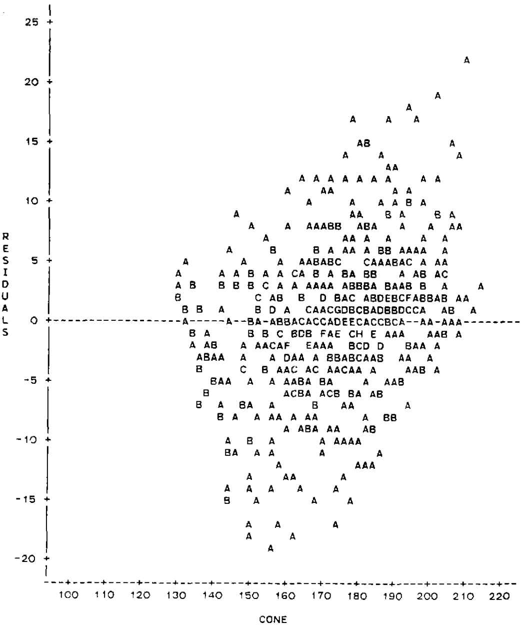
```
                                       SAS                                              2
                                                21:19 TUESDAY, JANUARY 30, 1990
                    PLOT OF PRED*CONE     SYMBOL USED IS P
                    PLOT OF CONE*CONE     SYMBOL USED IS *
```



NOTE: 907 OBS HIDDEN

Appendix D: SAS Analysis for Engineering Parameters 50% Oil

SAS 3
21:19 TUESDAY, JANUARY 30, 1990
PLOT OF RESID*CONE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix D: SAS Analysis for Engineering Parameters 50% Oil

SAS 4
21:19 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	1684836397	336967279	1322.507	0.0001
ERROR	619	157717674	254794.30		
C TOTAL	624	1842554071			

ROOT MSE	504.7715	R-SQUARE	0.9144
DEP MEAN	5839.215	ADJ R-SQ	0.9137
C.V.	8.64451		

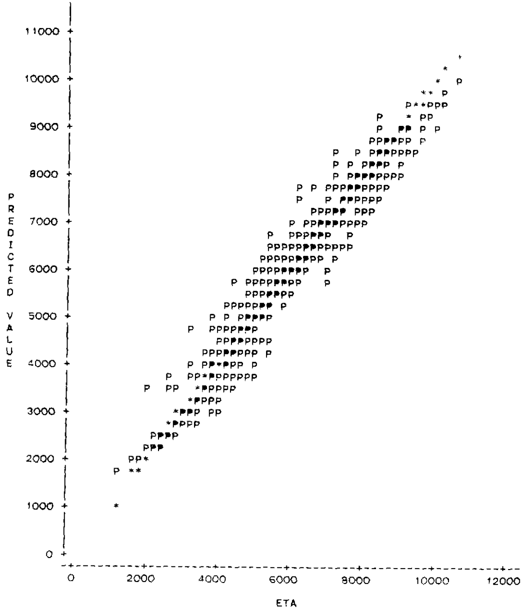
PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	5590.73747	324.36726	17.236	0.0001
DT	1	3617.76724	243.57574	14.853	0.0001
HXSH	1	0.01167595	0.03121196	0.374	0.7085
HXPS	1	-0.45155129	0.02124460	-21.255	0.0001
SUSH	1	-0.12396191	0.003381913	-36.654	0.0001
SUPS	1	12.33584960	0.43498287	28.359	0.0001

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	75692682.40	0
DT	1	56208617.24	7.18836775
HXSH	1	35655.96872	8.00929205
HXPS	1	115108323	1.07055884
SUSH	1	342327261	4.20475432
SUPS	1	204919621	3.46381501

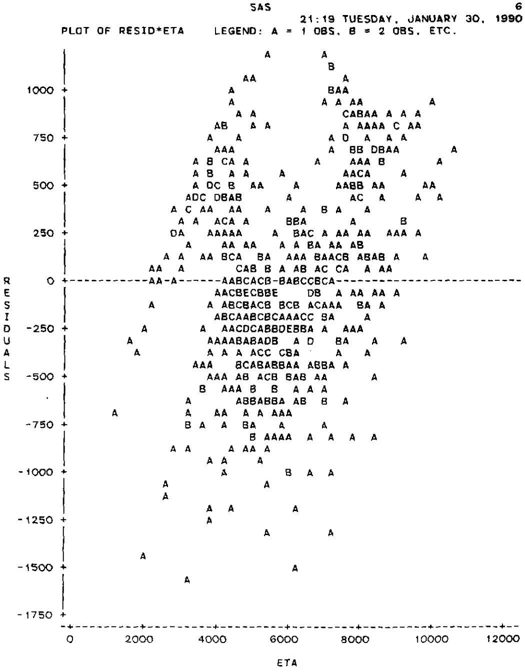
Appendix D: SAS Analysis for Engineering Parameters 50% Oil

```
                              SAS                                          5
                                   21:19 TUESDAY, JANUARY 30, 1990
                  PLOT OF PRED*ETA      SYMBOL USED IS P
                  PLOT OF ETA*ETA       SYMBOL USED IS *
```



NOTE: 949 OBS HIDDEN

Appendix D: SAS Analysis for Engineering Parameters 50% Oil



Appendix D: SAS Analysis for Engineering Parameters 40% Oil

```
1         SAS(R) LOG   OS SAS 5.18          MVS/XA JOB DIET      STEP SAS
                                                                    21:15

NOTE: COPYRIGHT (C) 1984,1988 SAS INSTITUTE INC., CARY, N.C.  27512, U.S.A.
NOTE: THE JOB DIET HAS BEEN RUN UNDER RELEASE 5.18 OF SAS
      AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 21  SERIAL = 172328  MODEL = 3090 .
      CPUID   VERSION = 21  SERIAL = 272328  MODEL = 3090 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

          OPTIONS LINESIZE=72,PAGESIZE=60;
          DATA DIET;
           DO SA=2 TO 4 BY .50;
              DO RPMS=200 TO 400 BY 50;
                 DO FLOW=8.75 TO 16.25 BY 1.875;
                    DO RPMW=275 TO 625 BY 87.5;
          CONE =  211.64
                  +(SA-3) * 15.365
                  +(RPMS-300)/100 * 12.125
                  -(FLOW-12.5)/3.75 * 21.0375
                  +(RPMW-450)/175 * 0.0875
                  -(SA*RPMS-3*RPMS-300*SA+900)/100    *6.125
                  +(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*8.7125
                  +(SA*RPMW-3*RPMW-450*SA+1350)/175   *0.7375
                  +(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 1.925
                  +(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 6.925
                  -(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375 * 2.2825
                  -(RPMS**2-600*RPMS+90000)/100**2 * 1.368
                  +(RPMW**2-900*RPMW+202500)/175**2 * 1.719
                  +(FLOW**2-25*FLOW+156.25)/3.75**2 * 1.469   ;
          ETA  =  2350.59
                  -(SA-3) * 743.9
                  -(RPMS-300)/100 * 627.813
                  +(FLOW-12.5)/3.75 * 772.44
                  -(RPMW-450)/175 * 117.188
                  +(SA*RPMS-3*RPMS-300*SA+900)/100    *399.56
                  -(SA*FLOW-3*FLOW-12.5*SA+37.5)/3.75*582.69
                  +(SA*RPMW-3*RPMW-450*SA+1350)/175   *91.688
                  -(RPMS*RPMW-300*RPMW-450*RPMS+135000)/17500 * 117.88
                  -(FLOW*RPMW-12.5*RPMW-450*FLOW+5625)/656.25 * 140.37
5
                  -(FLOW*RPMS-12.5*RPMS-300*FLOW+3750)/375    * 660.37
5
                  +(RPMS**2-600*RPMS+90000)/100**2 * 99.545
                  +(RPMW**2-900*RPMW+202500)/175**2 * 69.545
                  +(FLOW**2-25*FLOW+156.25)/3.75**2 * 26.670 ;
            DT = 27.778/ (SA * 0.0525 * 60.405/(FLOW/60))    ;
            HXSH = (56.541+23.16*RPMS/60-2.001*(RPMS/60)**2)
                   *(SA*0.0525*60.405/FLOW*60)               ;
            HXPS =  6*181.44*RPMS/60/(0.25**2*20.875)        ;
            SUSH = ((2*3.14159*1.1875*RPMW/60)/0.28125)
                   *(60.405*0.5828/FLOW*60)                  ;
            SUPS =  (2*3.14159*1.875*RPMW/60)/0.28125      ;
                  OUTPUT;
                END;
              END;
            END;
```

Appendix D: SAS Analysis for Engineering Parameters 40% Oil

```
2          SAS(R) LOG   OS SAS 5.18             MVS/XA JOB DIET
                                          21:15 TUESDAY, JANUARY 30, 1990

46          END;
47

NOTE: DATA SET WORK.DIET HAS 625 OBSERVATIONS AND 11 VARIABLES. 510 OBS/
TRK
NOTE: THE DATA STATEMENT USED 0.18 SECONDS AND 200K.

47          PROC REG DATA=DIET;
48             MODEL CONE = DT HXSH HXPS SUSH SUPS
49                        / VIF SS2;
50             OUTPUT OUT=PCONE P=PRED R=RESID;
51
NOTE: THE DATA SET WORK.PCONE HAS 625 OBSERVATIONS AND 13 VARIABLES.
      434 OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.15 SECONDS AND 452K
      AND PRINTED PAGE 1.

51             PROC PLOT DATA=PCONE;
52                PLOT PRED*CONE='P' CONE*CONE='*' / OVERLAY;
53                PLOT RESID*CONE /VREF=0;
54
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 2 TO 3.

54          PROC REG DATA=DIET;
55             MODEL ETA  = DT HXSH HXPS SUSH SUPS
56                        / VIF SS2;
57             OUTPUT OUT=PETA P=PRED R=RESID;
58
NOTE: THE DATA SET WORK.PETA HAS 625 OBSERVATIONS AND 13 VARIABLES. 434
      OBS/TRK.
NOTE: THE PROCEDURE REG USED 0.15 SECONDS AND 452K
      AND PRINTED PAGE 4.

58             PROC PLOT DATA=PETA;
59                PLOT PRED*ETA ='P' ETA*ETA='*' / OVERLAY;
60                PLOT RESID*ETA /VREF=0;
NOTE: THE PROCEDURE PLOT USED 0.12 SECONDS AND 204K
      AND PRINTED PAGES 5 TO 6.
NOTE: SAS USED 452K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27512-8000
```

Appendix D: SAS Analysis for Engineering Parameters 40% Oil

SAS 1
21:15 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: CONE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	258042.21	51608.44155	1164.153	0.0001
ERROR	619	27441.09085	44.33132610		
C TOTAL	624	285483.30			

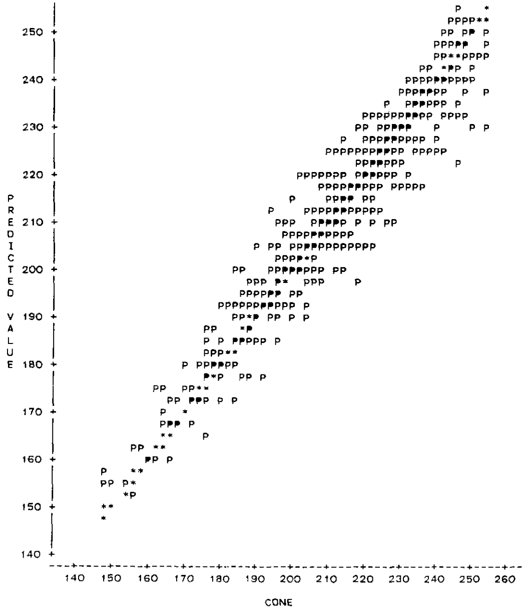
ROOT MSE	6.658177	R-SQUARE	0.9039
DEP MEAN	212.55	ADJ R-SQ	0.9031
C.V.	3.132523		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	230.28811	4.27855687	53.824	0.0001
DT	1	-79.17885376	3.32432388	-23.818	0.0001
HXSH	1	-0.000647053	0.000397899	-1.626	0.1044
HXPS	1	0.008835759	0.000280226	31.531	0.0001
SUSH	1	0.000468902	0.000043114	10.876	0.0001
SUPS	1	-0.05191305	0.005737632	-9.048	0.0001

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	128427.71	0
DT	1	25149.10209	7.18836775
HXSH	1	117.23164	8.00929205
HXPS	1	44073.77981	1.07055884
SUSH	1	5243.80309	4.20475432
SUPS	1	3629.09675	3.46381501

```
                              SAS                                2
                                    21:15 TUESDAY, JANUARY 30, 1990
              PLOT OF PRED*CONE     SYMBOL USED IS P
              PLOT OF CONE*CONE     SYMBOL USED IS *
```



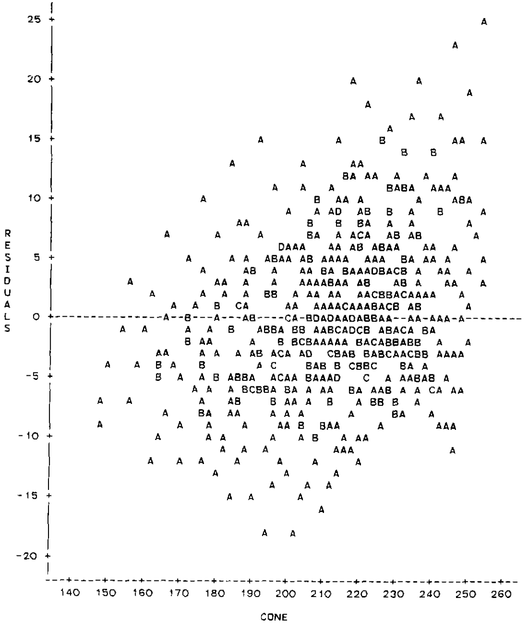
NOTE: 864 OBS HIDDEN

Appendix D: SAS Analysis for Engineering Parameters 40% Oil

SAS 3

21:15 TUESDAY, JANUARY 30, 1990

PLOT OF RESID*CONE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Appendix D: SAS Analysis for Engineering Parameters 40% Oil

SAS 4
21:15 TUESDAY, JANUARY 30, 1990

DEP VARIABLE: ETA

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	520555679	104111136	533.975	0.0001
ERROR	619	120688743	194973.74		
C TOTAL	624	641244423			

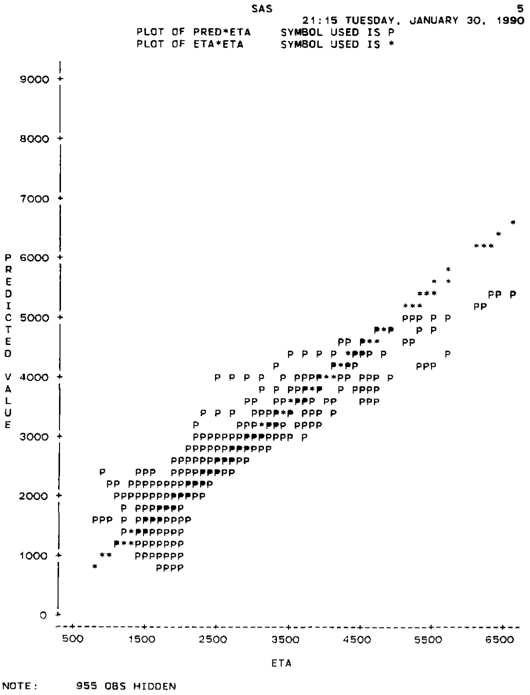
ROOT MSE	441.5583	R-SQUARE	0.8118
DEP MEAN	2448.47	ADJ R-SQ	0.8103
C.V.	18.03405		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	497.93408	283.74630	1.755	0.0798
DT	1	4937.82904	220.46316	22.398	0.0001
HXSH	1	0.19055863	0.02638794	7.221	0.0001
HXPS	1	-0.48589754	0.01858411	-26.146	0.0001
SUSH	1	-0.01114569	0.002859215	-3.898	0.0001
SUPS	1	0.29178759	0.38050937	0.767	0.4435

VARIABLE	DF	TYPE II SS	VARIANCE INFLATION
INTERCEP	1	600425.87	0
DT	1	97808401.83	7.18836775
HXSH	1	10167691.16	8.00929205
HXPS	1	133285206	1.07055884
SUSH	1	2962759.30	4.20475432
SUPS	1	114651.32	3.46381501

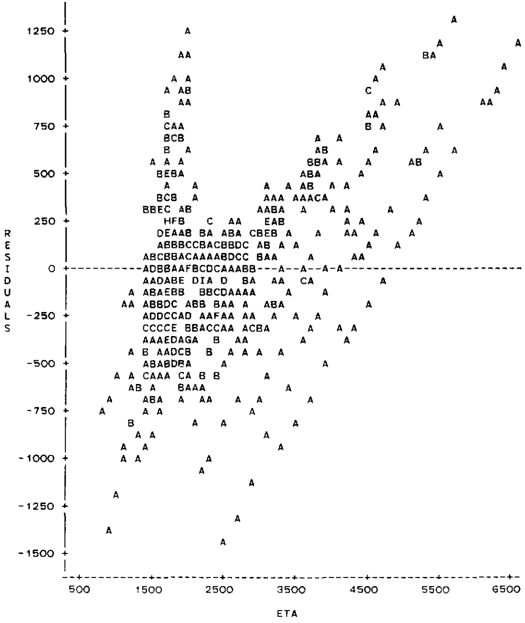
Appendix D: SAS Analysis for Engineering Parameters 40% Oil



Appendix D: SAS Analysis for Engineering Parameters 40% Oil

SAS 6
21:15 TUESDAY, JANUARY 30, 1990

PLOT OF RESID*ETA LEGEND: A = 1 OBS, B = 2 OBS, ETC.



VITA

Name: Gary Charles Garfield

Personal Data: Born: June 19, 1966
Parents: Janet L. Wilson
Gaynard D. Garfield

Education:
•M.S. Agricultural Engineering, Texas A&M University. May 1990.
•B.S. Agricultural Engineering, Food Engineering Option, Michigan State University. Received degree in June 1988.

Experience:
•Graduate Research Assistant. Texas A&M University, College Station, TX. (8/88-5/89 and 9/89 -12/89)

•Summer Engineer. Kraft Technology Center, Kraft General Foods Inc., Glenview, IL. (5/89-9/89, 6/88-8/88)

•Extrusion Research Manager. Michigan State University, E. Lansing, MI. (9/87-6/88)

•Summer Intern. Process Research Group, Nabisco Brands Inc., East Hanover, NJ. (6/87-9/87, 12/87)

Professional Societies:
American Society of Agricultural Engineering
Institute of Food Technologists'

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